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MATHEMATICS.—*The role of the concept of equivalence in the study of physical and mathematical systems.*[1]

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Foreword.—Many mathematicians as well as engineers and physicists sometimes fail to recognize the great principles underlying mathematical reasoning and methods that permeate their particular fields. Instead, they are apt to turn their attention solely to the formalism of the techniques involved. This is a tendency to be guarded against and one to which professional people and educators should give continued attention, particularly in the teaching of mathematics, science, and engineering. This paper, therefore, urges wider consideration of mathematical principles and methods by scientists and engineers, whether or not they are primarily interested in mathematics, and gives examples with reference to one well-known mathematical concept.[2]

1. *Introduction.*—The concept of equivalence lies at the heart of nearly every transaction, physical theory, and mathematical system. The literature abounds in such phrases as

(P) A is equivalent to B,

which, unless properly defined, are often meaningless or misleading (e.g., "an electric organ is equivalent to a pipe organ"; "one 1937 dollar is equivalent to 60 cents").

When S is a physical system, the elements $A, B, \ldots$ of the system are identified with specific physical objects, quantities, . . . , and the types of equivalence relations used must be carefully defined. Each such definition constitutes a separation of $A, B, \ldots$ and the associated physical picture into classes. Such separation may be of considerable physical significance, each type of equivalence often having associated with it an extensive physical theory. Thus, in electrical theory are defined: "equivalent m-pole networks," involving the "congruence" of certain matrices characterizing the physical system; "symmetric components," involving the "similarity" of certain matrices; etc.

In the study of physical systems, perfect, or approximate isomorphic (abstractly identical) systems play a fundamental role. Equivalent physical (or mathematical) models are integral parts of the methods used (e.g., as in hydrodynamic similitude theories, . . .).

Considerable progress has been made by mathematicians in extending the theory of equivalence relations. To what extent these abstractions will be of value in the applied fields remains to be seen. This much is clear. A consciousness of the concept of equivalence is of real value. It helps to clarify problems. It provides a means of attack. The involved details of the modern abstract theories of equivalence

[1] This paper was prepared from the manuscripts of two addresses by the writer: *The concept (and misconcept) of equivalence*, presented to the Philosophical Society of Washington on January 18, 1947, and *On the role of equivalence in pure and applied science and in practical and everyday life*, presented to the Oberlin Mathematics Club, Annual Banquet Meeting, on May 17, 1946. The writer wishes to express his appreciation of the many constructive suggestions and critical comments made during the preparation of the paper by his colleagues Dr. D. C. May, Mrs. A. B. McCaleb Nazary, and Miss A. Madsen, of the Bureau of Ordnance. The opinions expressed herein are those of the author and not necessarily those of the Navy Department. Received June 20, 1947.

[2] See also BURINGTON, RICHARD S., *New frontiers*, Science 101: 313–320. Mar. 30, 1945.

will be in themselves of little value in practical problems unless a penetrating inquiry into the economic, physical, or other pertinent background of the problem at hand is made.

2. *The phrase (P) must be defined.*—The phrase

(P) A is equivalent to B,

to have a well-defined meaning, requires appropriate definitions of the entities A and B, as well as a precise statement as to the meaning to be attached to the phrase "is equivalent to" as used in relation to A and B. Thus, the use of the phrase (P) should be accompanied by adequate and proper definitions. For example, in the phrase "1937 dollar is equivalent to 60 cents" it is not known what a "1937 dollar" is, what "60 cents" is, or what "is equivalent to" means. One would be at a loss to explain what the phrase means. Likewise, the phrase "an electric organ is equivalent to a pipe organ" is questionable since there is nothing in the statement indicating in what sense the two organs are considered to be equivalent. Does the phrase mean that the two organs can generate the same level of noise as measured (in some manner or other) in decibels in a given auditorium; does it mean that each of the two instruments can be used to play church music; or does it mean that their tonal potentialities are comparable to each other, and so on? The list need not be extended further, for the reader can no doubt contribute hundreds of similar examples and queries.

3. *Importance of such statements as (P).*—The importance of such statements as (P) becomes evident when one realizes that the notion of equivalence lies at the very basis of nearly every transaction and of nearly every mathematical system or formulation of a physical theory. For example, in order that the statement "3 feet = 1 yard" be understood, the concept of equivalent lengths must be thoroughly understood, and the fact that there exists standards of length, such as 1 foot and 1 yard, must be appreciated. A proper understanding of such statements as "$2\times3=6$" requires an accurate theory containing adequate definitions. Surely the operation of multiplying 2 by 3 is not "the same" as 6. If not "the same," then what is meant by the statement that $2\times3=6$? A complete answer to such questions requires a rather extensive treatment of the foundation of the theory of numbers. This will not be attempted here.

4. *Historical remarks on the definitions of equality.*—As man first attempted to discover the reasons for things, he began using the concepts of equivalence and identity. The philosophical considerations of these concepts have been debated at length. This phase of the subject is too vast to enter into here.

Leibnitz, in *Opera philosophica* (Erdmann) gave the definition: "Two things are called equal if, in every expression, one may be replaced by the other." This definition is open to much criticism.

Whitehead and Russell, in their *Principia mathematica* (1910), set forth a number of sets of postulates which an identity or an equality should satisfy. These postulates were developed over a period of time and were not original with Whitehead and Russell. A certain set of these postulates is, essentially, as follows:

I. Given any two elements A and B, either $A=B$ or $A\neq B$. (Determinative property.)
II. $A=A$. (Reflexivity property.)
III. If $A=B$, then $B=A$. (Symmetrical property.)
IV. If $A=B$ and $B=C$, then $A=C$. (Transitivity property.)

The critical student might well object to the use of these postulates as the basis for definitions of identity or equality. However, they are a great improvement over earlier definitions.

As MacDuffee[3] has pointed out, the teleological concept of equality has been favored by many mathematicians—until recently by most of them. (Teleology: the philosophical study of evidence of a coordinated creative design in nature.)

It should be noted that equality is sometimes taken as one of the basic principles of logic and not subject to further definition or analysis.

[3] MACDUFFEE, C. C., *Different kinds of equality*, The Mathematics Teacher, Jan. 1936: 10–13.

The newer approach to the subject is to define a new type of equality for the elements of some system. When this is done, it must be shown that the equality relation as defined actually has the required properties I, . . . , IV. This removes the concept completely from philosophical study.

5. *Abstract definition of the phrase (P).*—The abstract formulation of the notion of equivalence has been carefully studied by mathematicians. A brief outline of one such formulation seems appropriate for the purpose of this discussion, the formulation given being one commonly used in defining equivalence in algebraic systems, and in many formulations of physical theories.

One abstract formulation of this concept of *equivalence* may be embodied in the following four postulates and associated definitions.

Let $A, B, C, \ldots$ be elements in the fixed system S being considered (such as abstract entities, quantities, . . .), and suppose a possible relationship that may occur between these elements $A, B, C, \ldots$ is defined in some manner or other. Suppose that when A and B are so related, the relationship is indicated by the symbol $\underline{\mathrm{E}}$, and the expression $A \mathrel{\underline{\mathrm{E}}} B$ is written; and that when A and B are *not* so related, the fact is indicated by the symbol $A \mathrel{\not\underline{\mathrm{E}}} B$. Then the relationship expressed by the symbol $A \mathrel{\underline{\mathrm{E}}} B$ is known as the *equivalence* relation provided that it is defined to satisfy the following four *properties:*

I. *Determination.* For any pair of elements A and B of S the relation $A \mathrel{\underline{\mathrm{E}}} B$ either holds or does not hold.
II. *Reflexivity.* For any A one has $A \mathrel{\underline{\mathrm{E}}} A$.
III. *Symmetry.* When $A \mathrel{\underline{\mathrm{E}}} B$, then $B \mathrel{\underline{\mathrm{E}}} A$.
IV. *Transitivity.* When $A \mathrel{\underline{\mathrm{E}}} B$ and $B \mathrel{\underline{\mathrm{E}}} C$, then $A \mathrel{\underline{\mathrm{E}}} C$.

A is said to be equivalent to B if $A \mathrel{\underline{\mathrm{E}}} B$ is an equivalence relation.

[The symbol $\underline{\mathrm{E}}$ is to be read "is equivalent to"; the symbol $\not\underline{\mathrm{E}}$ is to be read "is not equivalent to."]

Every such definition of equivalence, which is ordinarily *not unique* for the given system, constitutes a division of the elements $A, B, C, \ldots$ into classes.

The determinative property (I) suggests the existence of at most two cases for the definition of equivalence used, and that the relation is *determinative.*

The reflexive property (II) is an extension of the earlier equivalence relation known as the *identity.*

The symmetric property (III) insures that the relation of equivalence is *symmetric.*

The transitive property (IV) is an extension of the old concept "things equal to the same thing are equal to each other."

The special equivalence relation $A \mathrel{\underline{\mathrm{U}}} B$, which is defined to hold for *any* pair of elements A and B is called the *universal relation.*

The equivalence relation $A \mathrel{\underline{\mathrm{I}}} B$, which holds only when A and B are the same or "identical elements," is called the *identity* or *unit relation.*

A serious study of systems which satisfy these properties would be a large undertaking. It would include study of systems that do not satisfy all these properties. Such an undertaking would involve a great many fields of mathematics. This will not be attempted in the present paper.

6. *Equality and equivalence.*—It should be remarked that the formulation given in paragraph 5 has been used to define the statement

(E) A is equal to B.

For the purposes of this paper the fine points of reasoning which have led some scholars to use the above postulates to define "is equal to" and others to use them to define "is equivalent to," and to distinguish between "is equal to" and "is equivalent to," need not be discussed here.

7. *Ordinary plane (Euclidean) geometry.*—Ordinary plane geometry when viewed from the newer point of view is crudely as follows:

(1) The elements of this geometry are points and lines forming geometric figures.
(2) The concept of superposition is taken for granted in such an intuitional geometry.
(3) Two geometric figures A and B are called *congruent* (equal) if one figure may be rotated and translated until it is brought into coincidence with the other figure.
(4) Given any two geometric figures A and B:
(a) Either these figures can be made to coincide ($A \mathrel{\underline{\mathrm{E}}} B$), or they can not be made

to coincide ($A \underline{E} B$). Thus the property of determination holds for the geometry under consideration.

(*b*) Every figure can be superimposed upon itself. ($A \underline{E} A$). Hence the property of reflexivity holds.

(*c*) If one figure can be made to coincide with a second figure, ($A \underline{E} B$), then the second can be made to coincide with the first, ($B \underline{E} A$). Thus the property of symmetry holds.

(*d*) If one figure can be made to coincide with a second figure, ($A \underline{E} B$), and the second figure can be made to coincide with a third figure, ($B \underline{E} C$), then the first can be made to coincide with the third, ($A \underline{E} C$). Hence, the property of transitivity holds.

Therefore, ordinary plane (Euclidean) geometry satisfies the four required properties of an equivalence relation as defined in paragraph 5.

(5) In this type of geometry, the geometry of congruent figures is the study of those properties relating to the figures which remain invariant under the equivalence relation of congruence. (Thus, if two triangles are congruent, their areas are equal.)

8. *Other examples from elementary geometry.*—In addition to the example given above there are many other simple examples of equivalence to be found in elementary geometry. Thus, in Euclidean geometry, two polygons A and B may be equivalent in the sense that they have equal areas, but they may or may not be equivalent in the sense that they have the same number of sides or angles, and so on.

Again, any two proper conics, A and B, are equivalent (that is $A \underline{E} B$) in the sense that A may be transformed into B by means of a projective transformation, while on the other hand A may or may not be equivalent to B in the sense that A may be transformed into B by means of a translation and rotation.

In general, in geometry, whether two geometric quantities are equivalent can be determined by calculating certain numbers known as invariants, which are associated with the objects under study. In such cases, if certain relative invariants for an object A are identical, respectively, to the corresponding invariants for the object B, the object A is equivalent to the object B. If these two sets of invariants are not identical, respectively, A is not equivalent to B.

For example, in ordinary translational geometry, two lines

$$ax+by+c=0, \tag{1}$$

and

$$dx+ey+f=0, \tag{2}$$

are equivalent in the sense of being parallel if, and only if, the ratio a/b is equal to the ratio d/e. These ratios are invariants of the lines (1) and (2), respectively, for a translational geometry.

Ordinary plane similarity geometry. The geometry of similar figures is a geometry quite distinct from ordinary Euclidean geometry. In this geometry the relation of similarity is easily shown to satisfy all four properties of an equivalence relation.

Other geometries. There are many other geometries, and the relationships of congruence used in them are examples of equivalence relations. Familiar examples of these types of geometries are projective, non-Euclidean, affine, and the like.

9. *Example from transportation.*—In order to show how these equivalence problems come up in practical fields outside of mathematical subjects, an example may be noted in the field of railroading. In the transportation literature many types of equivalence are commonly used. An example of current discussion in the transportation literature[4] is that of locomotive ratings, "equivalent locomotives." A number of methods of rating locomotives are commonly used, and much general confusion exists as the result of careless use of various types of equivalence relations.

Under present conventional systems of rating, a steam, a Diesel, and an electric locomotive, each locomotive rated as having "a 6,000 h.p. output," are actually only equivalent in the sense that the number 6,000 used happens to be the same, since the method of calculating the horsepower number is totally different in each case (one is cylinder output; the second is Diesel-engine output; the third is continu-

[4] WYNNE, F. E., *Comparable locomotive ratings*, Railway Age 120 (6): 316–318. Feb. 9, 1946.

ous output at rails; and each of them requires careful definitions).

If three locomotives are equivalent in the sense that they can each deliver the same useful output to the rail, they are not necessarily equivalent in the sense of their ability to handle the same weight of cars at 100 m.p.h. on level tangent track. And, if three locomotives are equivalent in this latter sense, they are not necessarily equivalent in the sense that they can deliver the same useful horsepower *continuously* at the rails; nor are they necessarily equivalent in the sense of their earning power, availability, reliability, etc.

Actually under present conventional systems of ratings, three locomotives having an advertised 6,000 h.p. output, one steam, one Diesel, one electric, while equivalent in the sense that the number of 6,000 is the same for all, are not equivalent in the sense of the weight of cars that they can handle at 100 m.p.h. on level tangent track continuously, the values actually being about 1,000 tons, 900 tons, 1,300 tons, respectively. Nor are they necessarily equivalent in their cost per ton mile hauled, availability ratio, etc. Furthermore, there are many other equivalence relations used in rating locomotives, all different, and many times badly misunderstood because of the lack, or omission, of good definitions. A general practical definition of "equivalent locomotives" has never been adequately given; and any such definition would doubtlessly involve the listing of many categories of equivalence and a scheme, or a set of schemes, for weighting these equivalences. A similar situation exists in many other fields.

10. *Equivalence in the elementary theory of sets.*—In the elementary theory of sets, one of the basic notions is that of equivalence. If the elements in two sets, A and B, can be paired with each other in such a manner that to each element of A there corresponds one and only one element of B, and to each element of B there corresponds one and only one element of A, then the correspondence is said to be *bi-unique*, and A and B are said to be *equivalent*.

Two finite sets have the *same number* of elements if and only if the elements of the two sets can be put into bi-unique correspondence. This is the idea of counting, for when one counts a finite set of objects one simply establishes a bi-unique correspondence between these objects and a set of number symbols $1, 2, 3, \ldots, n$. Thus, the notion of equivalence for finite sets corresponds to the ordinary notion of equality of numbers.

The concept of equivalence has been extended to infinite sets. This was done to construct an arithmetic of infinities. In this sort of theory there are just as many points on a straight line as there are real numbers. This means that the set of all real numbers and the set of all the points on a straight line are equivalent in the sense that, once an origin and a unit are chosen, a bi-unique correspondence between the real numbers and the points on the line can be made. With this understanding of equivalence, a finite set cannot be equivalent to any one of its proper subsets, for if the finite set contains n elements and no more, any one of its proper subsets can contain at most $n-1$ elements.

If a set contains infinitely many objects, it may be equivalent to a proper subset of itself. For example, there are just as many positive integers as there are positive even integers. This is easy to see from the bi-unique correspondence shown below.

$$\begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & \cdots & n & \cdots \\ \updownarrow & \updownarrow & \updownarrow & \updownarrow & \updownarrow & & \updownarrow & \\ 2 & 4 & 6 & 8 & 10 & \cdots & 2n & \cdots \end{array}$$

In fact, there are just as many rational fractions as there are integers. However, the set of all real numbers is not equivalent to the set of integers.

For those who wish to pursue this sort of equivalence theory, much can be found concerning the subject in the theory of sets (begun by George Cantor at the end of the nineteenth century).

11. *Algebra.*—Algebra furnishes many illustrations of the appropriateness of the concept of equivalence. Thus, if real positive numbers are assumed to be properly defined, then it is possible to introduce negative numbers in quite a logical manner by means of a certain definition for the equivalence of pairs of real positive num-

bers. Such a treatment may be found in the literature[5] and gives quite satisfactory answers to such questions as: Why does $(-1)(-1)=1$? A similar treatment based on the equality of pairs of real numbers can be formulated to give a logical introduction to complex numbers.

12. *Klein's definition of a geometry. Groups.*—In order to illustrate the connection between the theory of groups and the theory of equivalence further examples from geometry may be considered. Felix Klein (1871) defined geometry as the study of the invariants of a group of transformations. A *group* of transformations is a set such that:

1. The resultant transformation of two transformations is a transformation of the set.
2. The associative law holds.
3. There exists an identity transformation.
4. Every transformation has an inverse.

In ordinary Euclidean geometry, the transformations (of rotations and translations) form a group. Likewise in similarity geometry, the similarity transformations form a group. Thus, the geometry of congruent figures and the geometry of similar figures are examples of geometries as defined above.

13. *The resemblance between the definition of group and the definition of equivalence.*—This resemblance is a fundamental one. In associating an equivalence relation with a set of transformations, one associates with a set A of elements the set T of transformations which operates on A transforming it into some set B of elements. One might make a definition of equivalence by saying that B is equivalent to A if there exists a tranformation in the set T which transforms A into B, provided of course that the four properties of an equivalence relation are met. That this can be done, *if* and *only if* the transformations T form a group, can be shown readily.

It can be shown quite easily that:

THEOREM. *Equivalence relative to a group of transformations is an equivalence relation (satisfying properties I, II, III, IV).*

Something of what this theorem means may be illustrated by the following example:

[5] See C. C. MACDUFFEE, *loc. cit.*

Example. Consider the set of all real rotations T of the points in a plane about a fixed point O. This group may be represented by the equation

$$(T) \qquad w = ze^{i\theta}. \qquad (i^2 = -1).$$

By this formula any point z in the plane having polar coordinates ρ and α is rotated about the point O into a point w in the plane having polar coordinates ρ and $(\alpha+\theta)$.

That the set (T) of rotations form a group can be seen readily since:

1. The resultant of two rotations θ_1 and θ_2 is a rotation $\theta=\theta_1+\theta_2$ of the set (T).
2. The associative relation holds since for successive rotations, θ_1, θ_2, θ_3, $\theta_1+(\theta_2+\theta_3) = (\theta_1+\theta_2)+\theta_3$.
3. The rotation $\theta=0$ is the identity transformation.
4. Every rotation θ has the inverse rotation $(-\theta)$.

All points P in the plane at a fixed distance ρ from the point O could then be defined as equivalent with respect to the group of rotations (T) in the sense that any one point A of the points P can be transformed into any other point B of the set P by an appropriate rotation θ.

Thus, in this sense, all points on a circle with radius ρ and center O are equivalent to each other. But points on this circle are *not* equivalent to points on a circle with center at O and radius r where $r \neq \rho$. However, all points on the second circle are equivalent to each other in the sense defined.

That *this definition satisfies the four properties for an equivalence relation* follows since:

(A) Either two points in the plane fall on the same circle with center at O, or they do not. Thus property (I) is satisfied.

(B) Two coincident points lie on the same circle with center at O; hence property (II) is satisfied.

(C) When one point is equivalent to a second point they fall on the same circle with center at O; hence the second point is equivalent to the first point. Thus property (III) holds.

(D) When a point A is equivalent to a point B, they lie on a circle with center at O, and if B is equivalent to C they lie on a circle with center at O; hence A and C lie on the same circle since B lies on both circles with center at O. Thus property (IV) holds.

This example serves to illustrate the resemblance between the definitions of group and equivalence.

14. *Isomorphic systems.*—Another mathematical concept of considerable importance in its own right as well as in its applications is that known as *isomorphic systems.*

Consider two systems A and B each consisting of a set of elements and a set of

operations on these elements. Suppose that each system is closed with respect to a given system of operations in the system. The two systems A and B are said to be *isomorphic* or *abstractly identical* with respect to these operations if there exists a biunique one-to-one correspondence between the elements of A and B, such that any formal combination of, or operation on, the elements in A corresponds to the analogous construction with the corresponding elements in B.

In mathematics (such as in algebra) two isomorphic systems are commonly considered as equivalent; and the subject matter of mathematics, in this sense, may be considered as dealing with those properties of systems which are invariant (remain unchanged) for isomorphic systems.

15. *Applications to physical phenomena.*—In any specific situation the elements $a, b, c \ldots$ of a system S are identified with specific physical objects, numbers, quantities, entities, or the like, and the definitions of equivalence used must be carefully given in terms of these elements and the physical systems to which they belong. Each definition of equivalence used constitutes a separation of the set of elements $a, b, c, \ldots$ and associated physical phenomena or systems into classes. This separation into classes is often of considerable physical significance, each type of equivalence often having associated with it an extensive physical theory.

16. *Examples from circuit theory.*—As in mathematical theories, so in physical theories, many non-isomorphic types of equality have been and can be defined, each type of equality often having associated with it an extensive theory. Thus, in the theory of equivalent linear electrical circuits, two 2-pole networks may be equivalent[6] in the sense that for all frequencies they have identical driving-point admittances (or more generally, for $2N$-pole networks, that they have identical characteristic coefficient admittance matrices), *yet* they may not be equivalent in the sense that they have the same number of independent mesh circuits; or, are structurally the same; or, are equally economical to operate; or, are both readily physically realizable; and that if A and B respectively, are their network matrices, A and B may or may not be equivalent in the sense of matric congruence, . . .

Again in the theory of *symmetric components* as used in electrical engineering, the equivalence relationship used may often involve that of *matric similarity* between the matrices used to represent certain characteristics of the network in the various reference systems used in the theory. In this sort of equivalence the actual values of the voltages, currents, and impedances are left undisturbed, though the values of their representations in the various reference systems may be greatly different. Here the equivalence relation known as *matric similarity* is distinctly different from the equivalence relation known as *matric congruence*. Yet, both of these types of equivalence happen to be examples of another type of equivalence known as ordinary *matric equivalence*.

17. *Isomorphism as used in model studies. Principles of similitude.*—In the design of structures, bridges, ships, dams, flood control projects, and the like, the engineer, naval architect, and others responsible for the design must make accurate predictions as to the characteristics, cost, and performance of the various proposed designs. In such work the designers and planners can ill afford to make errors. Such projects are too expensive. Perhaps only one can ever be constructed. The final product must be right. It must do what it is designed to do, reliably, safely, and economically.

Engineers and scientists, in such instances, frequently take recourse to the construction and testing of models of the proposed structure. The results of the tests of the models are then used to predict the performance and characteristics of the proposed prototype. In order that a model test be of real use in predicting the properties of the prototype, great care must be exercised

[6] BURINGTON, RICHARD S., *Matrices in electric circuit theory*, Journ. Math. and Phys. **14** (4): 325–349. Dec. 1935; *A matric theory development of the Theory of Symmetric Components*, Philos. Mag. (ser. 7) **27**: 605. May 1939; *On circavariant matrices and circa-equivalent networks*, Trans. Amer. Math. Soc. **48** (3): 377–390. Nov. 1940.

in its design. Furthermore, considerable care is necessary in interpreting the measured and computed properties of the model test in terms of the prototype.

Theoretically, in designing a model test and in constructing the models for the test, every physical parameter of importance in the prototype must be considered and taken into account. It is not sufficient merely to make the dimensions of the model and prototype proportional. If a theory of similitude is not available, then one must be developed. Such a theory must serve as the basis for designing and constructing the model from its prototype dimensions. It must serve also as the guiding principle in interpreting the measurements made on the model in terms of the corresponding measurements as predicted for the prototype. If this theory of similitude is a perfect one, and the application of this theory is also perfect, then there is a one-to-one bi-unique correspondence between the various physical parameters of the prototype and the corresponding ones of the model; and every operation on or with the prototype has a corresponding operation on the model. In other words, any characteristic of the model as predicted through the isomorphism thus stated must be a true characteristic of the prototype, and vice versa. (This is an example of the equivalence property, if $A \underline{E} B$, then $B \underline{E} A$.)

In practice it is impossible to apply perfectly such a theory and expect the results predicted through the model test to be completely true for the prototype. A measure of this perfection lies in a comparison of the actual characteristics of the prototype with those predicted by the model studies. Consequently the aim in all such work is the construction of as near perfect an equivalent system of models as is humanly possible. In other words, these models must be as nearly isomorphic with their corresponding prototypes as possible.

An example where consideration is given to many physical parameters of importance may be found in hydrodynamics. In hydrodynamic studies, lengths L, a, b, c, . . . , time T, velocity V, mass M, force F, pressure increment p, mass density ρ, specific weight γ, viscosity μ, surface tension σ, and elastic modulus e for the object and fluid must be considered. (For convenience, L, M, F may be taken as the three fundamental dimensions.)

A number of theories of similitude have been developed for use in aero- and hydrodynamics. In one such theory, widely used, there is defined a certain set of dimensionless numbers

$$\pi_1=\frac{a}{b}, \cdots, \pi_4=\frac{\rho V^2}{p}, \quad \pi_5=\frac{V^2/a}{\gamma/\rho},$$

$$\pi_6=\frac{Va}{\mu/\rho}, \quad \pi_7=\frac{V^2a}{\sigma/\rho}, \quad \pi_8=\frac{V^2}{e/\rho}, \cdots,$$

which must be kept unchanged if true similarity (i.e., isomorphism) is to exist between the flow about the prototype and the flow about the model. In other words, if true similarity is to exist, every dimensionless parameter π_n, referring to conditions in the model, must have the same numerical value as the corresponding parameter for the prototype. This means, for one thing, that the model and prototype must be completely similar geometrically. To put the problem in another way, the set of dimensionless numbers $\pi_1, \ldots$ for the prototype must be identical with the corresponding set $\pi_1, \ldots$ for the model—if true similarity between prototype and model exists, and if predictions made from model studies are to be valid for the actual prototype. A mathematician would say that the parameters $\pi_1 \ldots$, must be absolute invariants for the prototype and model systems. Because the quantities $\pi_1, \ldots$, $\pi_n, \ldots$ are invariant for these isomorphic systems, the model and prototype systems are said to be equivalent.

Thus, if $\pi_1=a/b$ is to be invariant, where a and b are any two linear dimensions of the prototype, the corresponding linear dimensions a' and b' of the model must be so related that $\pi_1=a'/b'$. The reader can, for himself, discover other requirements on the model by merely holding each of the other parameters $\pi_2, \ldots$ fixed and interpreting the quantities in these parameters first, in terms of the prototype, and secondly, in terms of the model.

From a practical standpoint it is usually

impossible to realize fluids and values of the physical parameters of these fluids to satisfy *all* the requirements implied when the absolute invariance of the set $\pi_1, \ldots$ is demanded. This means that it is impossible to obtain a true model on any but the same scale using any but the same fluid as prototype. Of course, in this case, the model and the prototype would be equivalent. (This is an example of the equivalence property $A \underline{E} A$.) In spite of the difficulty and the knowledge that any practical model system cannot be made perfectly isomorphic with its prototype, much can be learned and reasonably reliable predictions can be obtained from such model studies.

In the testing of ship models and partly submerged objects, such as buoys and seaplanes, it has been found possible to make rather good predictions as to the behavior of the prototype by designing the model studies so as to keep the Froude number π_5 invariant. This compromise places the emphasis on the deminant physical parameters involved, namely, inertia and gravity forces, since π_5 is their ratio. In such work, π_4 known as Newton's number, can also be kept invariant. As a rule it is not possible to keep the remaining functions $\pi_2, \pi_3, \pi_6, \ldots$ invariant. This compromise means that the model system will be equivalent to the prototype system in the sense that the Froude and Newton's numbers are identical, respectively, for both the prototype and the model; but it does not mean that the prototype system and the model system are completely isomorphic otherwise.

When other physical parameters different from mass and inertia are considered to be of greater importance, then some other dimensionless numbers become of prime interest, and the functions π_4, π_5, corresponding to the two most important physical parameters are made absolutely invariant. Thus, in aerodynamics, emphasis is often placed on Reynold's number, π_6, rather than the Froude number π_5, since skin friction (viscosity) is then of prime importance. π_6 is the ratio of inertia and viscous forces.

Where inertia force and compressibility predominate, emphasis is placed on the Mach number, π_2, which is the ratio of the velocity of flow to the velocity of sound in the fluid at the given temperature.

18. *The use of equivalence principles in the design and testing of equipment.*—Aircraft, railway cars, and the like must be able to withstand great stresses and strains and much rough handling and must not be too vulnerable to damage from a great variety of causes. In designing such equipment a great deal of attention must be given to strength, safety, reliability, and costs, while recognizing economical and utilitarian values. Such considerations commonly involve various types of testing procedures designed to indicate the strength, reliability, etc, of vital portions of the equipment, as well as of the structure as a whole. Thus, the wings of an airplane or the axles of a truck can be tested in various ways for strength, ability to withstand shock, etc; the vulnerability of the fuselage or body to fire can be studied; and so on. But the results of such studies are only a partial indication of the strength and vulnerability of the airplane or car as a whole. Consequently, when possible, tests of the equipment as a whole are sometimes set up and the results obtained compared with the results of the tests of specific parts of the equipment. Of course, the ultimate test lies in the experience gained with the equipment under actual service conditions for a long period of time under a great variety of circumstances.

The quantities involved in criteria developed for use in testing may be quite different from the quantities available from over-all testing or from operational experience. An adequate theory for correlating (a theory of equivalence) these measures obtained in tests of specific parts and in over-all testing and experience must be formulated. Thus in attempting to measure, say, the ability of a car to withstand collision, controlled tests might be made in the laboratory, in which such parameters as energy, velocity, deformation, stress distribution, bending moments, momentum, pressure, and the like are used. Yet such parameters as these may not be available in examining the damage to such a car in collision; the only real information available being that which can be observed and de-

duced from the wreckage. The need for a theory for correlation (equivalence) is evident in such a case.

To summarize in connection with such test results there appears:

(1) The problem of the formulation of criteria and methods for describing, defining, and measuring such things as strength, safety, vulnerability to damage, . . . of the component parts of the equipment, as well as of the equipment as a whole.

(2) The problem of formulating principles for correlating these measures of strength, safety, damage, ... These measures may be observed in experiments—
  (a) with specific parts of the equipment,
  (b) with specific assemblies of the equipment,
  (c) with the equipment as a whole under test conditions,
  (d) with the equipment as used in actual operations.

In order that an adequate basis for reliably predicting the worth and safety of a design be realized, each of these major problems must be faced and an adequate solution obtained when at all possible. The construction of such a theory and mode of prediction, if it is to be a good one, must involve a careful use of the principles of equivalence. The importance of this procedure is all the more important since actual operational experience with a new design of certain types of equipment may be, costly (or even dangerous to human life) and such experience cannot always be made available before production.

Thus, in the field of design, testing, etc., there is a continuing need for the wise use of the principles of equivalence.

19. *Recent mathematical developments*[7].—In recent years much progress has been made by such mathematicians as Ore, MacDuffee, Garrett Birkhoff, and others in extending the analysis of the theory of equivalence relations. These extensions have served to connect rather diverse mathematical fields and have gone deeply into various fields of abstract algebra, topology, and related fields and apparently are leading to still a more general and abstract theory of mathematical relations. These investigations are of interest chiefly to workers in certain branches of pure mathematics. To what extent some of these abstractions will be of immediate value to workers in the applied fields remains to be seen. But this much seems clear, that: Consciousness of the concept of equivalence as outlined herein is of real value in many physical fields. It helps to clarify many problems. It provides a means of attack. It should be remarked, however, that the involved details in the development of the modern theory of equivalence relations will in themselves be of little value in practical and scientific problems unless a penetrating inquiry into the economic, physical, or other pertinent background of the problem at hand is made. This last point is of great importance.

To illustrate what is meant, consider the following well known mathematical results:

A *partition* P of the set S is a decomposition of S into subsets $C_1, \cdots, C_n, \cdots$ such that every element in S belongs to one and only one set C_n. The sets C_n are called *blocks* of the partition P, and $P = P(C_n)$ is written to indicate this.

THEOREM. *Any partition $P(C_n)$ defines an equivalence relation E in the set S when one puts $A \underline{E} B$ whenever A and B belong to the same block C_n. Conversely, any equivalence relation E defines a partition $P(C_n)$ where the block C_n consists of all elements equivalent to any given element A.*

This theorem tells us that there are many possible equivalence relations definable for a set S. Which particular equivalence relations are worth studying seriously will depend on the set itself and what general problems are under consideration. Thus, if S is the set of all locomotives, many types of equivalance relations can be defined, such as equivalence in the sense of the same cylinder output; or continuous output at the rails; or equivalence in the sense that they have, or do not have, brass trimming around the edge of the headlight; or equivalence in the sense that they can reach a maximum speed of 100 miles per hour, or not; or equivalence in the sense that the locomo-

[7] WHITMAN, P. M., *Lattices, equivalence relations and subgroups*, Bull. Amer. Math. Soc. 52 (6): 507–522. June 1946; ORE, OYSTEIN, *Theory of equivalence relations*, Duke Math. Journ. 9 (3). Sept. 1942; BIRKHOFF, GARRETT, *On the structure of abstract algebras*, Proc. Cambridge Philos. Soc. 31: 433–454. 1935; MACDUFFEE, C. C., *loc. cit.*

tives are named after some one, or are not; etc. Now obviously, some of these types of equivalence have some reason for existence, while others are of course trivial or ridiculous. To repeat the point: Involved details in the theory of equivalence relations will in themselves be of little value in practical problems unless a penetrating inquiry into the economic, physical, or other pertinent background of the problem at hand is made.

20. *Summary.*—The present paper discusses some of the meanings that may be attached to the phrase "*A* is equivalent to *B*." A glimpse of the mathematical properties that must be possessed by an equivalence relation has been shown. Isolated examples of equivalences in geometry, set theory, number theory, algebra, electrical networks, hydrodynamics, and engineering have been cited. Some attention has been given to the theories of modeling and similitude, which are so important in hydro- and aerodynamics, theories in which a form of equivalence known as *isomorphism* plays a leading role.

The use of either perfect or approximate isomorphic systems (or more general equivalent systems) appears as a fundamental process in almost all studies of physical phenomena. The method consists broadly of:

(1) The extraction from the physical phenomena *S* of a nearly isomorphic (equivalent) physical model *P*.
(2) Reduction of the physical model *P* to an isomorphic (equivalent) mathematical model *M* amenable to treatment.
(3) A solution of this mathematical system *M*.
(4) The interpretation of the solution found in (3) in terms of the mathematical model *M*.
(5) The interpretation of the solution found in (4) in the physical model *P*.
(6) Finally, the interpretation of the result (5) in the original physical settings.

Although at present it is not clear how much value the abstract extensions of the theory of equivalence relations will prove to be for use in the applied fields, it does appear that the theory will be beneficial in offering a background for the broad approaches to practical problems.

BOTANY.—*Studies in* Lonchocarpus *and related genera, II: Miscellaneous Middle American Lonchocarpi.*[1] FREDERICK J. HERMANN, U. S. Department of Agriculture.

The most extensive and generally useful of the comparatively recent partial treatments of the genus *Lonchocarpus* is Henri Pittier's *The Middle American species of Lonchocarpus* (Contr. U. S. Nat. Herb. **20**: 37-93. 1917). This monographic account embraces the 40 species known from Mexico and Central America 30 years ago, to which are appended a list of six excluded or doubtful species and detailed descriptions of nine related South American and West Indian Lonchocarpi. One of the first tasks of a current review of the genus as a whole is, therefore, to attempt to allocate within the framework of the classification proposed by the author of that work the miscellaneous species subsequently described by various other authors from the same area. In some cases the systematic position of a recently proposed species has been correctly indicated by its author and characteristics distinguishing it from its nearest allies may have been pointed out; in others lack of either flowering or fruiting material may have prevented this; in still others a misinterpretation, due either to faulty earlier descriptions or to the author's lack of comprehensive familiarity with the group, may vitiate the supposed relationship and hence sectional position or taxonomic status; and, finally, in some instances no attempt whatever has been made to indicate the relationship of the new species.

No discussion seems to be required here of such of these species as have been satisfactorily disposed of by other authors, such as *Lonchocarpus caribaeus* Urban (referred to the synonymy of *L. benthamianus* Pittier by Harms in Fedde Rep. Spec. Nov. **17**: 323. 1924), *L. capensis* M. E. Jones (shown to be actually *Tamarindus indica* L. by Morton in Contr. U. S. Nat. Herb. **29**: 103. 1945), *L. modestus* Standl. & Steyerm. (transferred to *Lennea* by its authors in

[1] Received July 8, 1947.

Fieldiana, Botany, **24** (5): 275. 1946), and *L. trifoliolatus* Standl. (equated with *L. phaseolifolius* Benth. by Standley and Steyermark in Fieldiana, Botany, **24** (5): 282. 1946). Six additional names (*L. argyrotrichus* Harms, *L. calderoni* Standl., *L. lindsayi* Standl., *L. obovatus* Benth., *L. salvinii* Harms, and *L. schiedeanus* (Schlecht.) Harms) have been recently transferred to *Willardia* by the writer (Journ. Washington Acad. Sci. **37**: 427. 1947), to which genus Standley (Contr. U. S. Nat. Herb. **23**: 483. 1922) had already referred *L. eriophyllus* Benth.

It seems desirable to present the conclusions of the writer upon the following additional eight species, particularly since certain original misinterpretations are being perpetuated in recent important floristic works such as the *Flora of Guatemala*.

Lonchocarpus amarus Standl., Carnegie Inst. Washington Publ. 461: 63. 1935 = VATAIREA LUNDELLII (Standl.) Killip *ex* Record (*Tipuana lundellii* Standl. l.c. 65).

Since the original material of *Tipuana lundellii* lacked flowers and that of *Lonchocarpus amarus* is without fruit, the failure to realize the identity of the two is readily understandable. The alternate leaflets, diadelphous stamens, wings of the corolla free from the keel, and the strikingly funnelform calyx of *Lonchocarpus amarus* definitely exclude it from that genus. Flowering specimens of *Vatairea lundellii* (collected since the publication of that species), kindly lent to the writer for study by the Chicago Natural History Museum, are identical with the type of *L. amarus*. *Vatairea lundellii* appears to be most nearly related to the Amazonian *V. fusca* Ducke, from which it is distinguishable by the appressed rather than spreading pubescence of the calyx, pedicels, and peduncles, by its broader wing petals (4.5 mm), by having the stamens definitely shorter than the pistil, and by the tendency of the calyx to split in the late-bud stage, between the vexillar teeth.

Lonchocarpus dumetorum Brandegee, Univ. California Publ. Bot. **10**: 181. 1922 = L. DARIENSIS Pittier, Contr. U. S. Nat. Herb. **20**: 69. 1917.

The type specimen of *L. dumetorum* (*Purpus 8591;* this and other Brandegee types reviewed through the courtesy of the University of California Herbarium) is a good match with that of *L. dariensis* (*Pittier 5515*, U. S. National Herbarium). It has, in addition to flowers and leaves, nearly mature legumes, which are very closely similar to those of *L. megalanthus* Pittier, this similarity bearing out Dr. Pittier's tentative alignment of it, in the absence of fruit, with the latter species. Both *L. dariensis* and *L. megalanthus*, however, as well as the closely related *L. mexicanus* Pittier, have leaflets conspicuously punctate, and so they could not be keyed out to his section Epunctati wherein he placed them. It seems probable that this is what led Brandegee to believe that he had an undescribed species in his *L. dumetorum*, and the same discrepancy may have been partly responsible for his proposal of *L. purpusii*.

Lonchocarpus izabalanus Blake, Contr. U. S. Nat. Herb. **24**: 7. 1922 = L. LUTEOMACULATUS Pittier, Contr. U. S. Nat. Herb. **20**: 64. 1917.

Lonchocarpus luteomaculatus is a highly variable species, almost as polymorphic in fact as its near ally *L. latifolius* (Willd.) HBK. The type of *L. izabalanus* is very similar to many recent collections of *L. luteomaculatus*. It was differentiated, in the original description, principally by the possession of a maroon banner with a green spot at the base instead of a purple banner with a basal yellow spot, but it seems likely that the flower color ascribed to *L. luteomaculatus* by its author was that of the dried plant and that in the fresh state it may be actually closer to the maroon-green pattern. At any rate, there now seems to be no distinguishable difference between the corolla colors of the two type specimens (*Blake 7841* and *Pittier 4170*, U. S. Nat. Herb.).

Lonchocarpus kerberi Harms, Fedde Rep. Spec. Nov. **17**: 322. 1921 = L. PENINSULARIS (Donn. Smith) Pittier, Contr. U. S. Nat. Herb. **20**: 56. 1917.

A fragment of the type of *L. kerberi* (*Kerber 35*) is fortunately preserved in the herbarium of the Chicago Natural History Museum. This is sufficiently ample to show that it is not at all related to *L. benthamianus* Pittier, *L. proteranthus* Pittier, and *L. punctatus* HBK., as supposed by Harms, and that it differs from the type of *L. peninsularis* (*Tonduz* s.n. (*Inst.*

Fls. Geogr. Costa Rica 18961), U. S. Nat. Herb.) only in the corolla being slightly less pubescent. It is not surprising that *L. kerberi* was regarded as a new species by its author and that its affinities were misinterpreted. Since it has leaflets that are not impressed-nerved and that are unmistakably punctate, its relationship with *L. peninsularis* would scarcely be suspected in view of the fact that the latter is placed by Pittier in his series Impressinervi and that his description includes no reference to the conspicuously punctate character of the leaflets mentioned by Donnell Smith in his original description of the species as *Derris peninsularis* (Bot. Gaz. **44**: 111. 1907). Actually, *Lonchocarpus peninsularis* and the likewise misplaced *L. nicoyensis* (Donn. Smith) Pittier and *L. costaricensis* (Donn. Smith) Pittier belong to the series Planinervi. Both *L. peninsularis* and *L. nicoyensis* fall into the section Punctati, the former being apparently most closely related to *L. longistylis* Pittier. It is doubtless due to the anomalous position in Pittier's classification of the frequently collected *L. peninsularis* that still another synonym of this species was created—*L. purpusii* Brandegee.

Lonchocarpus monospermus Standl., Field Mus. Publ. Bot. **4**: 311. 1929 = L. LUTEOMACULATUS Pittier, Contr. U. S. Nat. Herb. **20**: 64. 1917.

The distinguishing feature ("small one-seeded pods") attributed to *L. monospermus* is quite prevalent in *L. luteomaculatus*, the pods of the type specimen of *L. luteomaculatus* (*Pittier 4170*, U. S. Nat. Herb.) being predominently 1-seeded and 2.5 cm long. The type of *L. monospermus* (*Standley 53715*, Chicago Nat. Hist. Mus.) appears to differ in no tangible respect from this.

Lonchocarpus purpusii Brandegee, Univ. California Publ. Bot. **6**: 500. 1919 = L. PENINSULARIS (Donn. Smith) Pittier, Contr. U. S. Nat. Herb. **20**: 56. 1917.

The type specimen of *L. purpusii* (*Purpus 7849*, Univ. Calif.) is a very close match with that of *Derris peninsularis* in the U. S. National Herbarium. For discussion see *L. dumetorum* and *L. kerberi* above.

Lonchocarpus seleri Harms, Fedde Rep. Spec. Nov. **17**: 324. 1921 = L. HONDURENSIS Benth., Journ. Linn. Soc. **4**: Suppl. 91. 1860.

L. seleri was set off from *L. hondurensis* by Harms "durch fast sitzende Blüten auf längerem gemeinsamen Stiele und wohl auch grössere Vorblätten." Examination of a large series of *L. hondurensis*, however, shows the relative length of peduncle and pedicel to be very unstable; for example, *Mell 530* (U. S.) is *L. seleri* in its peduncles but not in its pedicels whereas *Wilson 706* (U. S.) is *L. seleri* in its pedicels but not in its peduncles. No difference was found between the bracts in the type fragment of *L. seleri* in the Chicago Natural History Museum (*Seler 5052*) and those of *L. hondurensis*, which are exceedingly variable.

Lonchocarpus xuul Lundell, Bull. Torrey Bot. Club **69**: 391. 1942.

The reference of this species to the synonymy of *L. guatemalensis* Benth. in the recently published *Flora of Guatemala* (Fieldiana, Botany, **24**(5): 278–279. 1946) seems to be clearly erroneous. The long stipes (averaging 1 cm) of the short, thick pods (generally 2.5–4 cm long) of *L. xuul* and its much smaller flowers set it off at a glance from *L. guatemalensis* with its sessile or subsessile, long, flat legumes (averaging 6–20 cm long). The author of *L. xuul* correctly indicated its close relationship with *L. constrictus* Pittier among the Middle American species. Its nearest ally in the genus as a whole is the Venezuelan *L. mirandinus* Pittier, with which it shows a striking similarity in its fruit but from which it differs in its few (5 to 9 rather than averaging 15), blunt leaflets and in its mainly green flowers.

The disposition of the following 17 binomials, the remainder of those proposed from Middle America since 1917, must be postponed either because no specimens have yet been procurable for study or because the material so far available has not been sufficient for more than tentative conclusions:

L. apricus Lundell, Lloydia **2**: 90. 1939. Chiapas, Mexico.

L. belizensis Lundell, Wrightia **1**: 55. British Honduras.

L. castilloi Standl., Tropical Woods **32**: 15. 1932. Guatemala; British Honduras.

L. chiapensis Lundell, Wrightia **1**: 152. 1946. Chiapas, Mexico.

L. cruentus Lundell, Wrightia **1**: 55. 1945. Tobasco, Mexico.

L. fuscopurpureus Brandegee, Univ. California Publ. Bot. **10**: 405. 1924. Veracruz, Mexico.

L. galleotianus Harms, Fedde Rep. Spec. Nov. 17: 322. 1921. Oaxaca, Mexico.
L. gillyi Lundell, Wrightia 1: 56. 1945. Chiapas, Mexico.
L. hidalgensis Lundell, Wrightia 1: 153. 1946. Hidalgo, Mexico.
L. hintoni Sandwith, Kew Bull. Misc. Inf. 1936: 4. 1936. Mexico and Guerrero, Mexico.
L. malacotrichus Harms, Fedde Rep. Spec. Nov. 17: 323. 1921. Mexico.
L. monofoliaris Schery, Ann. Missouri Bot. Gard. 30: 89. 1943. Panama.
L. nicaraguensis Lundell, Wrightia 1: 154. 1946 Nicaragua.
L. phlebophyllus Standl. & Steyerm., Field Mus. Publ. Bot. 23 (2): 56. 1944. Guatemala.
L. stenodon Harms, Fedde Rep. Spec. Nov. 17: 324. 1921. Oaxaca, Mexico.
L. whitei Lundell, Wrightia 1: 154. 1946. Nicaragua.
L. yoroensis Standl., Field Mus. Publ. Bot. 9 (4): 296. 1940. Honduras.

ZOOLOGY.—*On the crayfishes of the* Limosus *section of the genus* Orconectes (*Decapoda: Astacidae*).[1]

HORTON H. HOBBS, JR., Miller School of Biology, University of Virginia. (Communicated by FENNER A. CHACE, JR.)

In the course of working over a series of crayfishes from the Nashville, Tenn., area collected for me by Dr. C. S. Shoup, of Vanderbilt University, and Dr. Mike Wright, of Tusculum College, it was necessary to examine the type specimens of several of the species of the *Limosus* section. In making this study I arrived at certain conclusions, which are discussed below, concerning the affinities of the members of this section which are not in accord with the opinions of others. In addition to the description of a new species I am including a key to the species of the *Limosus* section.

The new species herein described was first reported by Fleming (1939) under the name *Cambarus propinquus sanborni* Faxon. I have compared my specimens with Fleming's description and figures which leave much to be desired. In addition, I have examined several crayfish he sent to the United States National Museum[2] from the only locality he cited for his *C. propinquus sanborni*, and I am convinced that his specimens were members of the species I am describing below. The only locality that Fleming recorded is "Mill creek, located about 4 miles south of Nashville where this creek crosses the Murfreesboro Road [U. S. Hy. 41], studied on August 18, 1935" (Fleming, 1939, 13: 298).[3]

[1] Received July 17, 1947.

[2] These are not the specimens mentioned by Fleming in his report of the higher Crustacea in the Nashville region, for he stated that Mill Creek was "studied on August 18, 1935," and these were collected on August 15, 1936.

[3] This peculiar citation is necessary because Fleming's paper was divided, and appeared in two volumes of the Proceedings of the Tennessee Academy of Sciences; an overlapping in page references causes a further complication. See "Literature Cited."

Genus **Orconectes** Cope 1872

Orconectes shoupi, n. sp.[4]

Cambarus propinkuus Fleming, 1939, 14: 305 (in part).
Cambarus propinquus sanborni Fleming (not Faxon), 1939, 14: 305, 306 (in part), 319, 320, and pl. 14.

Diagnosis.—Rostrum with lateral spines, margins thickened and concave laterad; upper surface with or without a median carina. Fingers of chela with usual longitudinal ridges much reduced; whole hand resembling that of *O. rusticus placidus* (Hagen, 1870: 65). Epistome with a median carina (see Fig. 4). Areola approximately 9 to 10 times longer than broad, with two or three punctations in narrowest part—length 34–36 percent of entire length of carapace; in male, hooks on ischiopodites of third pereiopods only. Terminal elements of first pleopod of first-form male short, reaching almost to coxopodite of second pereiopod. Two terminal elements separated for only a short distance near tip: mesial process recurved caudomesiad and shorter than central projection. Annulus ventralis immovable. (See Fig. 5 for surface contour.)

Holotypic male, form I.—Body subovate,

[4] Dr. C. S. Shoup has made a definite and worth-while contribution toward a knowledge of the fauna of the State of Tennessee. In token of the interest he has shown in my work on the crayfishes and the many specimens he has added to my collection, I name this new species in his honor.

distinctly depressed. Abdomen narrower than thorax. Width of carapace greater than depth in region of caudodorsal margin of cervical groove (15.2–9.4 mm).

Areola moderately narrow (9.6 times longer than broad), with two or three punctations in narrowest part; cephalic section of carapace about 1.8 times as long as areola (length of areola about 35.6 percent of entire length of carapace).

Rostrum with thickened margins concave laterad. Upper surface concave, but bearing a weak median carina. Base of acumen set off by corneous knoblike tubercles directed cephalodorsad. Acumen long and terminating cephalad in a corneous knob similarly disposed as the tubercles at its base. Subrostral ridges prominent and visible in dorsal aspect to base of acumen. Raised lateral margins of rostrum flanked laterally and mesially by rows of prominent setiferous punctations.

Postorbital ridges prominent, grooved dorsad and terminating cephalad in heavy acute tubercles. Suborbital angle absent. Branchiostegal spine obtuse, very much reduced. Small lateral spine present on each side of carapace. Surface of carapace granulate laterally and bearing prominent punctations dorsally; small polished area in gastric region.

Cephalic section of telson with two spines in each caudolateral corner.

Epistome bell-shaped in profile with a median longitudinal ridge; no cephalomedian projection.

Antennules of the usual form, with a small spine present on ventral surface of basal segment.

Antennae broken in holotype but extending caudad to cephalic margin of telson in other specimens. Antennal scale of moderate width with subparallel mesial and lateral margins; outer portion broad and swollen and terminating distad in a heavy spine; lamellar portion broad (see Fig. 9).

Chela somewhat depressed; palm inflated; prominent setiferous punctations present over most of chela. Inner margin of palm with three rows of squamous ciliated tubercles. Fingers widely gaping at base. Upper surface of immovable finger with a narrow well-defined ridge along mesial margin; lateral and lower margins with prominent punctations; upper opposable margin with a row of 18 rounded corneous tubercles; an additional prominent tubercle present below this row at base of distal fifth of finger; minute denticles occurring in a single row on penultimate fifth of mesial surface of immovable finger; mesial distal fifth with a broader zone of similar denticles; lower proximomesial surface bearded. Opposable margin of dactyl with 23 rounded corneous tubercles; distal half of mesial margin bearing minute denticles interspersed between the rounded tubercles. Otherwise dactyl similar to immovable finger.

Carpus of first pereiopod longer than broad, with a prominent longitudinal furrow on upper surface; all surfaces with scattered punctations. Mesial surface with a heavy spinous tubercle; distal upper mesial margin with a prominent rounded tubercle; lower distal margin with two heavy tubercles.

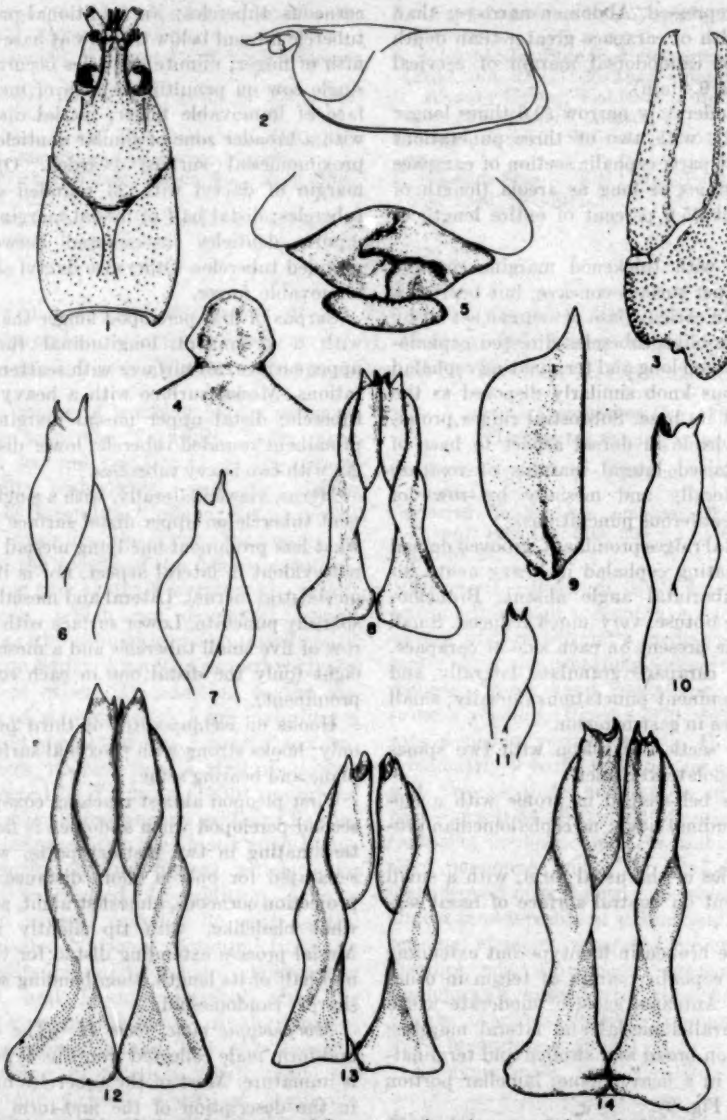
Merus, viewed laterally, with a single prominent tubercle on upper distal surface (a somewhat less prominent one lying mesiad of it but not evident in lateral aspect, nor is it present on sinistral merus). Lateral and mesial surfaces sparsely punctate. Lower surface with a lateral row of five small tubercles and a mesial row of eight (only the distal one in each row at all prominent).

Hooks on ischiopodites of third pereiopods only; hooks strong with proximal surfaces subplane and bearing setae.

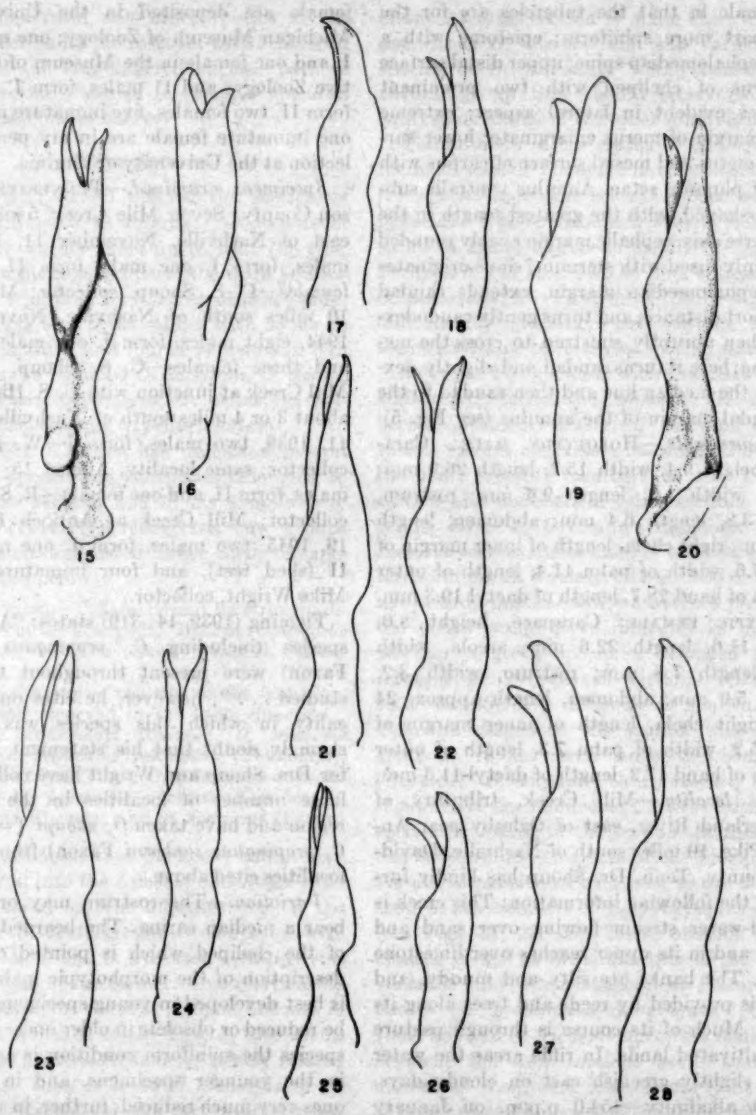
First pleopod almost reaching coxopodite of second pereiopod when abdomen is flexed. Tip terminating in two distinct parts, which are separated for only a short distance. Central projection corneous, almost straight, and somewhat bladelike, with tip slightly recurved. Mesial process extending distad for the proximal half of its length, then bending somewhat sharply caudomesiad.

Morphotypic male, form II.—The only second-form male collected from the type locality is immature. Most of the tubercles mentioned in the description of the first-form male are present in this specimen as acute spines. The lower surface of the carpus and the cephalomesial surface of the merus of the cheliped with tufts of long plumose setae. Rostrum without median carina. Hook on ischiopodite of third pereiopod very much reduced. See Figs. 16 and 19 for structure of first pleopod of a mature second-form male from Mill Creek.

Allotypic female.—Differs from the holo-



FIGS. 1–14.—1, Dorsal view of carapace of *Orconectes shoupi*, n. sp.; 2, lateral view of same; 3, upper surface of chela of first-form male, *O. shoupi;* 4, epistome of *O. shoupi;* 5, annulus ventralis of *O. shoupi;* 6, mesial view of first pleopod of first-form male of *O. pellucidus australis* (Rhoades), from McFarlen Cave, SW¼ NW¼ sec. 22, T. 3, R. 3 E., near Garth, Jackson County, Ala.; 7, mesial view of first pleopod of first-form male of *O. pellucidus pelluicdus* (Tellkampf), from Mammoth Cave, Roaring River, Edmonson County, Ky.; 8, caudal view of first pleopods of first-form male, *O. pellucidus packardi* Rhoades (holotype), from Cumberland Crystal Cave at Alpine, Pulaski County, Ky.; 9, antennal scale of *O. shoupi;* 10, mesial view of first pleopod of first-form male, of *O. inermis* Cope, from Seibert's Well Cave near Wyandotte Cave, Crawford County, Ind.; 11, mesial view of first pleopod of first-form male of *O. pellucidus packardi* Rhoades (holotype) (see explanation of Fig. 8); 12, caudal view of first pleopods of first-form male of *O. pellucidus pellucidus* (Tellkampf) (see explanation of Fig. 7); 13, caudal view of first pleopods of first-form male of *O. pellucidus australis* (Rhoades) (see explanation of Fig. 6); 14, caudal view of first pleopods of first-form male of *O. inermis* Cope (see explanation of Fig. 10).



FIGS. 15–28 (all figures except 15, 16, and 19 lateral views of the first pleopods of first-form males).—15, Mesial view of first pleopod of first-form male of *Orconectes shoupi*, n. sp.; 16, same, second-form male; 17, *O. harrisoni* (Faxon), from stream at Irondale, Washington County, Mo.; 18, *O. sloani* (Bundy), from Little Creek, Jefferson Township, Preble County, Ohio; 19, lateral view of first pleopod of second-form male of *O. shoupi;* 20, *O. shoupi;* 21, *O. rafinesquei* Rhoades (holotype), from Rough River, at Falls-of-Rough, Grayson-Breckinridge Counties, Ky.; 22, *O. limosus* (Rafinesque), from Leman Place, Lancaster County, Pa.; 23, *O. tricuspis* Rhoades (holotype), from Pete Light's Spring, 3 miles east of Canton, Trigg County, Ky.; 24, *O. indianensis* (Hay), no locality given, U.S.N.M. no. 44448; 25, *O. propinquus propinquus* (Girard), from Rocky Creek, Muncie County, Ill.; 26, *O. difficilis* (Faxon), from stream 1 mile south of Wilburton, Latimer County, Okla.; 27, *O. kentuckiensis* Rhoades (holotype), from Piney Creek, 3 miles west of Shady Grove, Crittenden County, Ky.; 28, *O. sloani* (Bundy), Indiana (probably from near New Albany), U.S.N.M. no. 58058.

typic male in that the tubercles are for the most part more spiniform; epistome with a small cephalomedian spine; upper distal surface of merus of cheliped with two prominent tubercles evident in lateral aspect; extreme distal margin of merus emarginate; lower surface of merus and mesial surface of carpus with tufts of plumose setae. Annulus ventralis subspindle-shaped, with the greatest length in the transverse axis; cephalic margin evenly rounded and firmly fused with sternum; sinus originates near cephalomedian margin, extends caudad for a short distance, and turns gently caudodextrad, then abruptly sinistrad to cross the median line; here it turns caudad and slightly dextrad to the median line and then caudad to the midcaudal margin of the annulus (see Fig. 5).

Measurements.—HOLOTYPIC MALE: Carapace, height 9.4, width 15.2, length 26.9 mm; areola, width 1.0, length 9.6 mm; rostrum, width 3.8, length 6.4 mm; abdomen, length 27.7 mm; right chela, length of inner margin of palm 7.5, width of palm 11.4, length of outer margin of hand 28.7, length of dactyl 19.3 mm. ALLOTYPIC FEMALE: Carapace, height 8.0, width 11.6, length 22.6 mm; areola, width 0.70, length 7.8 mm; rostrum, width 3.2, length 5.9 mm; abdomen, length approx. 24 mm; right chela, length of inner margin of palm 5.2, width of palm 7.3, length of outer margin of hand 17.2, length of dactyl 11.3 mm.

Type locality.—Mill Creek, tributary of Cumberland River, east of Oglesby near Antioch Pike, 10 miles south of Nashville, Davidson County, Tenn. Dr. Shoup has kindly furnished the following information: This creek is a hard-water stream flowing over sand and rubble and in its upper reaches over limestone ledges. The banks are silty and muddy, and shade is provided by reeds and trees along its banks. Much of its course is through pasture and cultivated lands. In riffle areas the water has a slightly greenish cast on cloudy days. (M. O. alkalinity—154.0 p.p.m. on January 24, 1947.)

Disposition of types.—The holotypic male, the allotypic female, and the morphotypic male, form II, are deposited in the United States National Museum (no. 84072), and in addition five second-form males and one female, collected by R. S. Fleming (U.S.N.M. no. 77908) are designated as paratypes. Of the remaining paratypes, one male, form I, and one female are deposited in the University of Michigan Museum of Zoology; one male, form I, and one female in the Museum of Comparative Zoology; and 11 males, form I, one male, form II, two females, five immature males, and one immature female are in my personal collection at the University of Virginia.

Specimens examined.—TENNESSEE, Davidson County: Seven Mile Creek, 5 miles southeast of Nashville, November 11, 1944, two males, form I, one male, form II, and two females—C. S. Shoup, collector; Mill Creek, 10 miles south of Nashville, November 11, 1944, eight males, form I, one male, form II, and three females—C. S. Shoup, collector; Mill Creek at junction with U. S. Highway 41, about 3 or 4 miles south of Nashville, October 11, 1939, two males, form I—W. K. Smith, collector; same locality, August 15, 1936, five males, form II, and one female—R. S. Fleming, collector; Mill Creek at Antioch Pike, July 19, 1945, two males, form I, one male, form II (shed test), and four immature males—Mike Wright, collector.

Fleming (1939, 14: 319) states: "All of these species (including *C. propinquus sanborni* Faxon) were present throughout the region studied . . . "; however, he cites only one locality in which this species was taken. I strongly doubt that his statement is correct, for Drs. Shoup and Wright have collected in a large number of localities in the Nashville region and have taken *O. shoupi* (= Fleming's *C. propinquus sanborni* Faxon) from only the localities cited above.

Variation.—The rostrum may or may not bear a median carina. The bearded condition of the cheliped which is pointed out in the description of the morphotypic male, form II, is best developed in young specimens and may be reduced or obsolete in older ones. As in most species the spiniform condition is accentuated in the younger specimens, and in the older ones very much reduced; further, in some of the females mirrored images of the annulus ventralis as described for the allotype occur.

Relationships.—Orconectes shoupi is a member of the *Limosus* section; it possesses short gonopods, the tips of which are separated for only a short distance. Its closest affinities are with *O. sloani* (Bundy) (1876:24), *O. tricuspis* Rhoades (1944:117), and *O. rafinesquei* Rhoades (1944:116). *O. shoupi* may readily be

distinguished from any other species of the *Limosus* section by the rostrum with thickened ridges and the long-fingered chelae—both of which resemble those of *O. rusticus placidus*. (see further remarks below.)

LIMOSUS SECTION

Ortmann (1931:64) defined the section of *Orconectes limosus* as follows: "Gonopods of male, short, rather thick up to near the tips, reaching to the coxopodites of the third peraeopod. Tips separated for a short distance only, each tapering to a point. Males with hooks on third, or on third and fourth peraeopods." In this section he included *O. harrisoni*, *O. sloani*, *O. indianensis*, *O. limosus*, *O. pellucidus pellucidus pellucidus*, and *O. pellucidus testii*.

Since 1931 Rhoades has described several additional species and subspecies belonging to the *Limosus* section, and in his *Crayfishes of Kentucky* (1944:117) recognized two groups of the section, and listed under them the species indicated below:

Limosus group—"characterized by strongly diverging tips of the gonopods." Species: *O. limosus* (Rafinesque), *O. sloani* (Bundy), and *O. indianensis* (Hay).

Rafinesquei group—"the tips of the first pleopod are both recurved in the same direction." Species: *O. rafinesquei* Rhoades, *O. tricuspis* Rhoades, *O. pellucidus pellucidus* (Tellkampf), *O. pellucidus testii* (Hay), *O. pellucidus australis* (Rhoades), *O. pellucidus packardi* Rhoades, *O. kentuckiensis* Rhoades, and *O. harrisoni* (Faxon)

It is questionable that the above subdivision of the section into the *Limosus* and *Rafinesquei* groups is based on true affinities: e.g., if the pleopod of *O. kentuckiensis* is compared with that of *O. sloani* and *O. tricuspis*, certainly it is more like that of the former. This relationship is seen not only in the first pleopod but also in the annuli ventralis of the two. It also seems to me that *O. harrisoni* is more nearly related to *O. sloani* than it is to *O. tricuspis* or *O. rafinesquei*. Except for the fact that the terminal elements of the first pleopods of the several subspecies of *O. pellucidus* are "recurved in the same direction" (and I might indicate that among the specimens I have examined of *pellucidus pellucidus* the terminal elements are straight), I can see no indication of closer affinities of these forms with the members of the *Rafinesquei* group than with those of the *Limosus* group—in fact, if any division of the *Limosus* section is made then it would seem that *O. inermis* and the various subspecies of *O. pellucidus* would constitute a natural group that should receive a status equivalent to that of the other subdivisions.

The problem of the status of *O. inermis* remains unsolved. Though I have seen relatively few specimens of the several subspecies of *O. pellucidus* I have examined several belonging to all of them, and none are like *O. inermis*. Perhaps it will be shown to be a subspecies of *O. pellucidus*; however, until future work will indicate intergradation between the two, it seems advisable to retain its specific status.

As might be expected, with the discovery of additional species the *Limosus* section has become decidedly less clear cut, and certain species exhibit characters transitional between the more typical members of the *Limosus* section and members of other sections of the genus. Even in Ortmann's diagnosis of the *Limosus* section quoted above the best character is stated on a relative basis, and a worker not already familiar with an over-all picture of the genus would have difficulty in deciding whether a given specimen belonged to the *Limosus* or *Propinquus* sections (Ortmann, 1931: 64, 65). The difficulty at the time that Ortmann diagnosed the section was not so great as it has been since the somewhat "atypical" *O. tricuspis*, *O. rafinesquei*, and *O. shoupi* have been added to the list of described species belonging to the section. In these species the terminal elements of the first pleopod are almost as slender and long as are those of some of the members of the *Propinquus* section (see Figs. 21, 23, 25). These obvious resemblances as well as the similarities of the annuli ventralis and other anatomical features between *O. propinquus propinquus* (Girard, 1852: 88) and *O. tricuspis* make the distinction between the two sections seem somewhat unnatural—i.e., there seem to me to be about as many resemblances between *O. tricuspis* and the subspecies of *O. propinquus* as between *O. tricuspis* and *O. sloani*, *O. limosus*, and *O. indianensis*. Furthermore, considering the pleopods alone, *O. kentuckiensis* is transitional between *O. limosus* and *O. sloani* on one side and *O. difficilis* (Faxon, 1898: 656) on the other—the latter at present being relegated to the *Virilis* section (Ortmann, 1931: 90). Rhoades (1944: 123) states in reference to the

affinities of *O. kentuckiensis* that it "represents a more advanced stage in the series of the 'Group rafinesquei'. The tips are stouter and more differentiated and the annulus is more depressed as in *sloani* and other members of the 'Group limosus'. In this character it resembles closely *O. immunis immunis*. Furthermore, it is not difficult to see a possible affinity to the 'Section of *C. virilis*' [=*O. virilis*] even in the gonopods of the male."

Whether these similarities are results of convergence or whether they indicate actual close relationships can hardly be determined until a more exhaustive study of the group (which will necessarily mean extensive collecting) is made. On the basis of the evidence at hand I find it difficult to consider these resemblances arising independently in the three sections.

The taxonomists working with the crayfishes of the Cambarinae have for a long time found it convenient to recognize "sections," "groups," and "subgroups," and even though there are certain species that on the bases of the diagnostic characters appear to be intermediate between two sections or groups, at least a temporary retention of their usage seems desirable. Whereas the limits of variation in the three sections of the subgenus *Orconectes* are not decidedly marked, and almost impossible to define in words, recourse to determined specimens or figures should alleviate difficulty in determining to which section or group any specimen in question belongs. For this reason I am including a sketch of the pleopods of all the species and subspecies (except *O. pellucidus testii*, of which I do not have a first form male) belonging to the *Limosus* section, and in addition, for comparative purposes, the pleopods of *O. propinquus propinquus* and *O. difficilis*.

KEY TO THE SPECIES AND SUBSPECIES OF THE LIMOSUS SECTION OF ORCONECTES

(BASED ON THE FIRST-FORM MALE)

1. Body pigmented, eyes well developed.....2
   Body not pigmented, eyes reduced.....9
2. Terminal elements of first pleopod subequal in length and distinctly divergent (central projection directed cephalodistad and mesial process caudodistad).....3
   Terminal elements of first pleopod subequal or not subequal in length, but central projection never bent cephalodistad—either straight, directed caudad, or caudodistad..4
3. Lateral surface of carapace with only one spine.....*O. indianensis* (Hay)
   Lateral surface of carapace with more than one spine.....*O. limosus* (Rafinesque)
4. Central projection bent caudad at an angle greater than 45°.....*O. harrisoni* (Faxon)
   Central projection directed distad or bent caudad at an angle less than 45°.....5
5. Terminal elements of first pleopod subequal in length or mesial process slightly longer than central projection.....*O. tricuspis* Rhoades
   Mesial process never extending quite so far distad as central projection.....6
6. Central projection recurved (caudodistad) throughout its length; no median carina on rostrum....*O. kentuckiensis* Rhoades
   Central projection not recurved caudodistad throughout its length; median carina on rostrum present or absent.....7
7. Margins of rostrum thickened and concave laterad.....*O. shoupi* Hobbs
   Margins of rostrum not thickened, and subparallel or convergent up to base of lateral spines.....8
8. Terminal elements of first pleopod widely separated and thick (heavy); tip of mesial process caudomesiad of central projection.....*O. sloani* (Bundy)
   Terminal elements of first pleopod not widely separated, and slender and tapering; tip of mesial process caudolaterad of central projection.....*O. rafinesquei* Rhoades
9. Margins of rostrum uninterrupted; acumen not distinctly set off from rest of rostrum.....*O. pellucidus testii* (Hay)
   Margins of rostrum interrupted; acumen distinctly set off from rest of rostrum.....10
10. Cephalic margin of pleopod without a shoulder at base of central projection; however, either straight or curved.....11
    Cephalic margin of pleopod with an angular or rounded shoulder.....12
11. Cephalic surface of first pleopod in region of central projection straight; mesial process directed distad and extending distad beyond central projection.....*O. pellucidus pellucidus* (Tellkampf)
    Cephalic surface of first pleopod in region of central projection curved; mesial process directed caudodistad and somewhat laterad, and not extending distad beyond central projection.....*O. inermis* Cope
12. Shoulder on cephalic margin at base of central projection rounded; hooks present only on ischiopodites of third pereiopods.....*O. pellucidus australis* (Rhoades)[5]

[5] The holotype of *O. pellucidus australis* has a small short acute spine (probably corresponding to the caudal process seen in many members of the genus *Procambarus*), which in lateral aspect lies between the central projection and the mesial process.

Shoulder on cephalic margin at base of central projection distinctly angular; hooks present on ischiopodites of third and fourth pereiopods. *O. pellucidus packardi* Rhoades.

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ORNITHOLOGY—*The races of the black-throated sunbird,* Aethopyga saturata *(Hodgson).*[1]

H. G. DEIGNAN, U. S. National Museum.

For more than 30 years the race of *Aethopyga saturata* common on the mountains of northwestern Siam has, without any direct comparison of specimens, been recorded as *sanguinipectus* (a name originally applied to the form of the Karen Hills). Topotypes of *sanguinipectus* and of its presumed synonym *waldeni* (described from Mount Muleyit in Tenasserim) are nowhere available in America, but reference to the first descriptions and especially to Shelley's *Monograph of the Nectariniidae,* pt. 6, 1878, pp. 37–38 and colored plate (where the description is taken from the types of *sanguinipectus* and the illustration from the types of *waldeni*), has shown that *sanguinipectus* has the entire throat (except only the center of the chin) metallic blue or violet and is thus quite different from the Siamese bird, as well as from the several populations of Indochine that have been masquerading under its name. This discovery has made necessary a revision of the species, with the result that the number of races has been increased from the five accepted by Delacour (Zoologica 29: 34. 1944) to nine, of which three are here described for the first time.

[1] Published by permission of the Secretary of the Smithsonian Institution. Received June 10, 1947.

Material essential to the prosecution of this study has been courteously sent me by the Museum of Comparative Zoology (M.C.Z.), the American Museum of Natural History (A.M.N.H.), the Princeton Museum of Zoology (P.M.Z.), the Academy of Natural Sciences of Philadelphia (A.N.S.P.), and the Chicago Natural History Museum (C.N.H.M.).

1. Aethopyga saturata saturata (Hodgson)

[*Cinnyris*] *Saturata* Hodgson, India Rev. and Journ. Foreign Sci. and Arts 1 (7): 273. Oct. 1836 (Nepal).

Nectarinia hodgsonis [*sic*] Jardine, Naturalist's Library 36 [Nectariniidae]: 240, 269 [where spelled *hodgsoni*], pl. 28, 1843 (Nepal).

Range. Himalayas, from Garhwal to Bhutan.

Remarks. The reference to Hodgson's name is incorrectly cited by Stuart Baker (Fauna of British India, birds, ed. 2, 7: 285. 1930) as "Ind. Review, vol. ii, p. 273, 1837." Sherborn (Index Animalium, p. 5753) gives "India Rev. I. 1837, 273." According to the researches of the late C. W. Richmond, the first volume of the India Review appeared in 12 monthly installments from April 1836 to March 1837, and the proper citation is that given above.

2. Aethopyga saturata assamensis (McClelland)

Cinnyris assamensis McClelland, Quart. Journ.

Calcutta Med. and Phys. Soc. 1 (3): 322. July 1837 (Assam). *Nomen nudum!*

Cinnyris Assamensis McClelland, Proc. Zool. Soc. London 7: 167. Mar. 1840 (Assam; type locality here restricted to the neighborhood of Sadiya, Sadiya Frontier Tract, Assam Province, India).

Range.—Assam; Burma (north); Yunnan (west).

Remarks.—Mayr (Ibis 1938: 302) has shown that the bird of northern Burma, while most like *saturata*; differs from it by a broadening of the yellow band across the lower back and by a slightly shorter wing and a much shorter tail. For this population the old name *assamensis* may be revived.

3. Aethopyga saturata sanguinipectus Walden

Æthopyga sanguinipectus Walden, Ann. Mag. Nat. Hist. (4) 15: 400. June 1875 ("Tonghoo hills [Karen-hee]," error; type locality corrected to "the Tonghoo and Karen-nee hills" by Wardlaw Ramsay, *in* The ornithological works of Arthur, Ninth Marquis of Tweeddale, p. 414, 1881).

Æthopyga Waldeni Hume, Stray Feathers 5 (1): 51. Apr. 1877 (Mount Muleyit, Amherst District, Tenasserim Division, Burma).

Range.—Southeastern Burma, from lat. 19° N. south to lat. 14° N. (but see Remarks).

Remarks.—Shelley (*loc. cit.* in introductory paragraph above) has observed that "the illustrations of both sexes are taken from the specimens collected by Mr. Davison, and described as *Æ. waldeni* by Mr. Hume, who has kindly forwarded them to me from India to compare with the types of *Æ. sanguinipectus*, to which species they evidently belong." It may be hoped that some latter-day students in London will compare the two again to learn whether they belong to the same *subspecies!*

The one bird of *sanguinipectus*-type available to me is a male from Mount Nwalabo (lat. 14° N.), which may or may not be properly placed under this name. The synonymy and range given above for *sanguinipectus* must therefore be considered only tentative.

4. Aethopyga saturata anomala Richmond

Æthopyga anomala Richmond, Proc. U. S. Nat. Mus. 22: 319. May 12, 1900 (Khao Sung, peninsular Siam at lat. 7°32′ N., long. 99°50′ E.).

Range.—Specimens are known from Khao Soi Dao (lat. 7°20′ N., long. 99°50′ E.), Khao Nok Ra (lat. 7°25′ N., long. 99°55′ E.), Khao Nam Pliu (lat. 7°35′ N., long. 99°50′ E.), and the type locality, all hills in the range dividing the Siamese provinces of Phatthalung and Trang.

5. Aethopyga saturata wrayi Bowdler Sharpe

Æthopyga wrayi Bowdler Sharpe, Proc. Zool. Soc. London 1887, pt. 3: 440, pl. 38, fig. 2. Oct. 1 (Larut Range, at elev. 4,400 ft., Perak State, Malaya).

Range.—Mountains of Malaya from northern Perak to southern Selangor and in Pahang.

6. Aethopyga saturata petersi, n. subsp.

Type.—C.N.H.M. no. 76209, adult male, collected at Pa Kha (lat. 22°32′ N., long. 104°18′ E.), Laokay Province, Tongking, on December 28, 1929, by J. Delacour and P. Jabouille (original number 3312).

Diagnosis.—The adult male of the new form is immediately distinguishable from those of *A. s. saturata* (Nepal), *A. s. assamensis* (Assam), and *A. s. anomala* (peninsular Siam) by having the lower breast sulphur yellow, conspicuously streaked with blood red.

From those of *A. s. sanguinipectus* (Karen Hills) and *A. s. johnsi* (southern Annam) it is separable by having the entire area between the metallic-blue mustachial streaks, from chin to breast, unglossed black (*not* metallic blue).

It is, in fact, nearest the geographically remote *A. s. wrayi* (Malaya), from which it may be known by its having the sulphur-yellow breast patch more clearly defined and posteriorly more extensive, the red streaks on the breast patch more numerous, and the remaining under parts a slightly paler, more yellowish, less grayish, olive green.

Range.—Yunnan (southeast); Tongking; Annam (north); Haut-Laos; Southern Shan States (Kengtung State); northern Siam (Chiang Rai and Nan Provinces).

Specimens examined.—34 males, 3 females.

Remarks.—This race is named in honor of James Lee Peters, of the Museum of Comparative Zoology.

7. Aethopyga saturata galenae, n. subsp.

Type.—U.S.N.M. no. 331074, adult male, collected on Doi Langka (Khao Pha Cho), northern Siam at lat. 19°00′ N., long. 99°25′ E.,

on November 10, 1930, by Hugh M. Smith (original number 4307).

Diagnosis.—The adult male is nearest that of *A. s. petersi* (Tongking) but differs by having the sulphur-yellow breast patch posteriorly more extensive and less clearly defined from the remaining underparts, which are olivaceous-yellow (*not* grayish olive-green).

The adult female is separable from that of *A. s. petersi* by having the underparts suffused posteriorly with yellow, rather than a uniform grayish olive-green.

Range.—Siam (northwest).

Specimens examined.—18 males, 3 females.

Remarks.—Of four males from Doi Ang Ka (lat. 18°35′ N., long. 98°30′ E.), three are inseparable from topotypical *A. s. galenae;* the exceptional specimen has the majority of the feathers of the upper half of the throat wholly or partly metallic blue and thus shows approach to *A. s. sanguinipectus-waldeni* of Mount Muleyit. It is highly probable that birds of the unexplored hills lying between Ang Ka and Muleyit will prove to be true *sanguinipectus-waldeni.*

This race is named in honor of my mother.

8. **Aethopyga saturata ochra,** n. subsp.

Type.—C.N.H.M. no. 91613, adult male, collected at Thateng (lat. 15°31′ N., long. 106°22′ E.), Saravane Province, Bas-Laos, on November 26, 1931, by J. Delacour (original number 312).

Diagnosis.—The adult male is nearest that of *A. s. galenae* (northwestern Siam), from which it differs (and so much the more from that of *A. s. petersi*) by having the sulphur-yellow breast patch posteriorly still more extensive and scarcely defined at all from the remaining underparts, which are more strongly suffused with yellow then in any other race.

The adult female seems to be identical with that of *A. s. galenae.*

Range.—Bas-Laos (Boloven Plateau).

Specimens examined.—7 males, 2 females.

9. **Aethopyga saturata johnsi** Robinson and Boden Kloss

Æthopyga sanguinipectus johnsi Robinson and Boden Kloss, Ibis (11) 1 (4): 621. Oct. 23, 1919 (Dran, Haut-Donai Province, southern Annam).

Range.—Southern Annam (Langbian Plateau).

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

THE ACADEMY

413TH MEETING OF BOARD OF MANAGERS

The 413th meeting of the Board of Managers, held in the Cosmos Club, December 15, 1947, was called to order at 8:10 P.M. by the President, Dr. WALDO L. SCHMITT. Others present were: H. S. RAPPLEYE, H. A. REHDER, H. B. COLLINS, Jr., F. G. BRICKWEDDE, F. L. MOHLER, J. S. WADE, W. W. RUBEY, L. E. YOCUM, W. A. DAYTON, M. A. MASON, C. L. GARNER, and C. L. GAZIN.

Eighteen persons were elected to membership. Dr. PERCY W. BRIDGMAN, a member of the Academy and a Nobel Prize winner, who has spoken before the Academy, was proposed for Honorary Membership. The Board voted unanimously that he be awarded this distinction. Ten nominations for resident membership were presented.

The Secretary, Dr. C. L. GAZIN, reported the death of Dr. DWIGHT F. WINDENBURG on November 14, 1947, formerly with the David Taylor Model Basin. He also reported the resignations of Drs. ALBERT E. LONGLEY and JOHN B. MERTIE, Jr. The Board accepted these resignations, with regret, effective December 31, 1947. The request of Dr. H. C. OBERHOLSER, who has paid dues from 1906 through 1947 and who has retired from the gainful practice of his profession, that he be placed on the retired list of Academy members was approved by the Board.

The Secretary announced that he received, on November 28, 1947, the nomination of Dr. GILBERT GROSVENOR for President of the Academy in 1948. [This candidate subsequently withdrew.—Ed.]

The Treasurer, H. S. RAPPLEYE, requested that he be authorized to transfer the present two investment certificates, amounting to $5,000 in total, in the First Federal Savings &

Loan Association, to a single account-book form as proposed by the Association. This request was granted.

The meeting was adjourned at 9:42 P.M.

C. L. GAZIN, *Secretary.*

NEW MEMBERS OF THE ACADEMY

There follows a list of persons elected to membership in the Academy, by vote of its Board of Managers, since December 16, 1946, who have since qualified as members in accordance with the bylaws. (See also previous list in May 15, 1947, issue of the Journal.) The bases for election are stated with the names of the new members.

RESIDENT

Elected December 16, 1946

WALTER A. MCCUBBIN, botanist, Bureau of Entomology and Plant Quarantine, in recognition of his contributions to the scientific basis of plant quarantines and the means of distribution of parasitic fungi.

DEAN B. COWIE, physicist, Department of Terrestrial Magnetism, Carnegie Institution of Washington, in recognition of his work in the construction of the cyclotron at the Department, for many cooperative researches in which cyclotron products made by him were used, and especially his work on the distribution of antimony in Filaria infections.

Elected January 13, 1947

MARK W. WOODS, botanist, National Cancer Institute, in recognition of his studies on the cytology of plant virus diseases and the origin and nature of viruses.

JOHN W. ALDRICH, biologist, U. S. Fish and Wildlife Service, in recognition of his contributions to knowledge of the taxonomy and distribution of North American birds.

Elected April 14, 1947

PHILIP DRUCKER, anthropologist, Bureau of American Ethnology, Smithsonian Institution, in recognition of his contribution to the ethnology of the Northwest coast and to the archaeology of these regions and of Veracruz, Mexico.

HARRIET L. FRUSH, chemist, National Bureau of Standards, in recognition of her contribution to organic chemistry, more especially the development of the first satisfactory mechanism for the production of orthoesters from transacetohalogen compounds and the development of methods for the separation of manuric and galacturonic acids.

CAMILLE L. LEFEBVRE, botanist, Bureau of Plant Industry, Soils, and Agricultural Engineering, in recognition of his researches in plant pathology, especially fungous diseases of forage crops.

CURTIS W. SABROSKY, entomologist, Bureau of Entomology and Plant Quarantine, in recognition of his contributions to the classification of the Diptera and in particular his work on the taxonomy of the family Chloropidae.

WALTER B. LANG, geologist, U. S. Geological Survey, in recognition of the pioneer study of the stratigraphy and sedimentation of the Permian of the Southwestern United States and its application to the discovery of potash and the development of a self-sufficient potash industry.

LOUISE M. RUSSELL, entomologist, Bureau of Entomology and Plant Quarantine, in recognition of her contributions to the taxonomy of the sternorhynchous Homoptera, in particular her studies on the classification of the coccid genus *Asterolecanium*, on various groups of the whitefly family Aleyrodidae, and on various species of the Psyllidae.

GEORGE M. FOSTER, Jr., anthropologist, Institute of Social Anthropology, Smithsonian Institution, in recognition of his contributions to the development of the science of ethnology in Mexico.

FENNER A. CHACE, Jr., biologist, U. S. National Museum, in recognition of his contributions in zoology, especially in the field of Crustacea.

RUTH E. GORDON, bacteriologist, Bureau of Plant Industry, Soils, and Agricultural Engineering, in recognition of her contributions to bacteriology, especially her researches on the acid-fast and on the spore-forming bacteria.

Elected October 6, 1947

HUBERT R. SNOKE, engineer, National Bureau of Standards, in recognition of his important work on roofing and building materials.

ELLIOTT B. ROBERTS, engineer, U. S. Coast and Geodetic Survey, in recognition of his contributions in the development of oceanographic instruments and techniques, and in exploration

and geodetic surveying in the Philippine Islands, the Aleutian Islands, and other areas.

CURTIS J. HUMPHREYS, physicist, National Bureau of Standards, in recognition of his work on spectroscopy, including Zeeman effect and intensity measurements in the spectrum of the solar chromosphere.

RICHARD K. COOK, physicist, National Bureau of Standards, in recognition of his contributions to acoustics and in particular to the absolute measurement of sound intensity.

NONRESIDENT

Elected October 6, 1947

THEODORE E. WHITE, paleontologist, Museum of Comparative Zoology, Cambridge, Mass., in recognition of his contributions to vertebrate paleontology, in particular to the morphology of primitive tetrapods.

PHILOSOPHICAL SOCIETY

1268th Meeting

The 1268th meeting, the occasion of the Fifteenth Joseph Henry Lecture, was held in the Auditorium of the U. S. National Museum, May 25, 1946, President DEFANDORF presiding.

Program: HARVEY FLETCHER, Bell Telephone Laboratories: *The pitch, loudness and quality of musical tones.* This paper has been published in full in the American Journal of Physics **14**: 215–225. 1946.

1269th Meeting

The 1269th meeting was held in the Cosmos Club Auditorium, October 12, 1946, President DEFANDORF presiding.

Program: H. W. WELLS, Department of Terrestrial Magnetism: *Panoramic ionospheric recorder.*—The application of a new technique for ionospheric research, developed at the Department of Terrestrial Magnetism, Carnegie Institution of Washington, under sponsorship of the United States Army Signal Corps, has led to the discovery of hitherto unsuspected rapid motions and fluctuations. The panoramic ionospheric recorder in development, operating over a range 1.0 to 20.0 megacycles per sec and registering the ionospheric echoes on a single frame of 16-mm motion-picture film, was described briefly. This apparatus makes two records each minute in normal operation. Projection of the series of 16-mm records thus obtained as a motion picture gives a condensation of time scale and a continuity of events which reveal ionospheric fluctuations of a surprising nature.

During periods of ionospheric and magnetic storms, rapidly moving clouds are "tracked" into the F2 (outer) layer. Upon merging of the clouds with the F2 layer the ionization is seen to increase, and downward rippling motions suggest an extension of the effect into lower regions of the ionosphere.

The technique of recording offers considerable promise both as a research tool leading to a better understanding of atmospheric physics and as an educational aid in training of personnel for ionospheric investigations. (*Author's abstract.*)

NEWBORN SMITH, National Bureau of Standards (paper read by Mr. SILBERSTEIN): *Longitude effect in F2-layer characteristics.*—Before adequate world-wide ionospheric observations had been made, it was assumed that the monthly average F2-layer critical frequencies and virtual heights were the same, at the same local time, for stations at the same geographic latitude but different longitudes. Radio operating data indicated, however, that this assumption was questionable, and ionospheric observations from the world-wide network of stations established during the war showed a pronounced longitudinal variation, apparently associated with differences in geomagnetic latitude. This paper presented the evidence for the longitude effect, indicating how it led to the operational use of separate ionospheric prediction charts for the different world zones. (*Author's abstract.*)

1270th Meeting

The 1270th meeting was held in the auditorium of the Cosmos Club, October 26, 1946, President DEFANDORF presiding.

Program: N. P. HAYS, Wright Field: *Polar navigation.*—Major Hays discussed his part as navigator in the preparations and flight of the Pacusan Dreamboat from Oahu to Cairo by way of the geomagnetic pole. (*Secretary's abstract.*)

SIR ROBERT WATSON-WATT, Radio Board of Great Britain: *Air navigation by radio methods.*—The early history, development, and use of radio were discussed. The use of radio reflections from the ionosphere and other small

reflections was also emphasized. (*Secretary's abstract.*)

1271st Meeting

The 1721st meeting was held in the auditorium of the Cosmos Club, November 9, 1946, President DEFANDORF presiding.

Program: J. H. CURTISS, National Bureau of Standards: *High-speed digital computing machines, Pt. 1.*—The chief purpose of this paper was to list and describe the various current Federally financed projects in the field of automatic digital computing machines. Those already in existence, listed in the approximate order of completion, are: the "IBM Automatic Sequence Controlled Calculator" at Harvard University; two small Bell Telephone Laboratories relay computers, of which one is at the Naval Research Laboratory and the other is at Fort Bliss, Tex.; five small relay calculators developed by the International Business Machines Corporation, of which one is at the Naval Proving grounds at Dahlgren, two are at the Ballistics Research Laboratory of the Aberdeen Proving Grounds, and two are at Watson Laboratories in New York City; and finally, the electronic "ENIAC," built at the University of Pennsylvania for Aberdeen. Two large Bell Telephone relay computers are almost finished; one is for Aberdeen and the other for the Langley Memorial Laboratory of N.A.C.A. Harvard University is constructing a large relay machine for the Naval Proving Grounds.

Important development projects are: (1) At the National Bureau of Standards, construction of large-capacity digital computers for the U. S. Navy and the Bureau of the Census, and a component development project for the Ordnance Department of the Army; (2) at the University of Pennsylvania, construction of another electronic digital computer for Aberdeen; (3) at the Institute for Advanced Study and RCA Laboratories at Princeton, N. J., construction of an electronic digital computer; (4) at the Massachusetts Institute of Technology, construction of a large electronic digital simulator for the Navy and also a component research project financed by the Rockefeller Foundation. (*Author's abstract.*)

S. N. ALEXANDER, National Bureau of Standards: *High-speed digital computing machines, Pt. 2.*—There are two basic approaches by which scientific computations can be reduced to an automatic operation. These are the analogue and the digital procedures. The analogue procedure had been exploited to the greater extent prior to the war. During the war the need for greater accuracy and flexibility led to intensive development of the digital procedure. The first of these machines, using electromechanical devices, was developed jointly by Harvard University and the International Business Machines Corporation. Next, the Bell Telephone Laboratories developed a computing machine using electrical relays. Finally, an essentially electronic machine of greatly increased operating speed was constructed at the University of Pennsylvania for the Army Ordnance. These applications of electromechanical and electronic techniques pointed the way toward making available the flexibility that is inherent in the digital procedure. An immediate goal is to apply this flexibility to the solution of partial differential equations. To accomplish this will require the development of still faster electronic machines of much greater capacity. Consequently, the present program for the development of large-scale, high-speed digital computing machines is being pursued with even more vigor than during the war. (*Author's abstract.*)

1272d Meeting

The 1272d meeting was held in the auditorium of the Cosmos Club, November 23, 1946, President DEFANDORF presiding.

Program: R. J. SEEGER, Naval Ordnance Laboratory: *Shock-wave phenomena.*—A significant property of linear differential equations is the principle of superposition of solutions, e.g., Huygens's principle in physics. Is there a corresponding principle in the case of nonlinear differential equations? Shock-wave phenomena presents a means of studying this question from the viewpoint of Nature's own integrations. This paper formed essentially a report of the research along this line initiated at the Bureau of Ordnance (Navy Department) by J. VON NEUMAN. It started with optical illustrations of shock waves occurring in ballistics, air jets, wind tunnels, and explosions. The mathematical concept of a shock wave was presented, leading to the simple step-shock model described by the Rankine-Hugoniot equations. This model has been used in the investigation

of the interaction of shock waves. The theoretical predictions for reflection from a rigid wall were compared with the experimental observations. For so-called regular reflection the simple model is adequate. In the case of Mach reflection, which involves an intersection of three shock waves (and a temperature discontinuity) moving away from the wall, there is an enigma that can not be solved by any simple physical picture such as uniform pressure between the shocks or even by Prandtl-Meyer modification of this uniformity. (*Author's abstract.*)

F. J. WEYL, Naval Ordnance Laboratory: *Optical analysis of supersonic flow.*—The variations in density, which will be found whenever a compressible fluid is engaged in nonuniform motion, imply accompanying variations in the local index of refraction. Consequently a beam of transluminating light will be disturbed by the presence of flow without, in its turn, disturbing the flow. This fact is used in three basically different fashions, depending on the optical apparatus inserted into the light path, to obtain records of the density variations in the compressible flows. Referred to as the shadowgraph, the schlieren, and the interferometric methods, they render visible respectively the total distortion, the change in direction, and the change in the time of transit experienced by the transluminating light beam on account of the presence of the flow. These three methods were first discussed from a quantitative analytic viewpoint and were then illustrated individually by typical records allowing a direct comparison of their respective strengths and weaknesses. (*Author's abstract.*)

1273d Meeting

The 1273d meeting, the 76th annual meeting, was held in the auditorium of the Cosmos Club, December 7, 1946, President DEFANDORF presiding.

The report of the treasurer, confirmed by the report of the auditing committee, showed an income from dues and interest on investments of $1357.54 and expenditures of $1137.20, leaving a net gain of $220.34 on ordinary expenses. The ordinary expenses were at the rate of $3.27 per member. The total estimated assets of the Society showed a decrease of $271.76 from $16,694.19 as of December 1, 1945, to $16,377.43 as of December 1, 1946.

The joint report of the Secretaries showed an active membership of 359 as of December 1, 1946—a net increase of 12 members during the year. The following persons were elected during the year: W. D. APPEL, C. E. BARTHELL, R. D. BENNETT, T. J. CARROLL, G. E. DAVIS, R. F. GELLER, P. H. GIROUARD, D. HARKIN, W. N. HARRISON, MARY W. HODGE, H. J. HOGE, R. L. MCKINNEY, D. E. PARSONS, G. W. PETERSON, E. K. PLYLER, B. P. RAMSAY, E. B. ROBERTS, L. H. RUMBAUGH, G. B. SABINE, G. H. SHORTLY, H. S. STEWART, R. D. STIEHLER, E. J. STOVALL, JR., R. WELLER, F. J. WEYL, W. J. WYATT.

The Secretaries reported the deaths of PAUL BROCKETT, W. N. HAMILTON, and W. P. WHITE.

Following the report of the Committee on Elections, these officers were declared elected for the year 1947: *President*, FRED L. MOHLER; *Vice-Presidents*, WALTER RAMBERG and KENNETH L. SHERMAN; *Recording Secretary*, WALTER L. CHENEY; *Treasurer*, FRANK C. KRACEK; *Members-at-Large of General Committee*, KARL F. HERZFELD, and LAWRENCE A. WOOD.

Program: R. P. PETERSON, Johns Hopkins Applied Physics Laboratory: *Exploration of the upper atmosphere by rockets, Pt. 1.*—A review of the advancements in cosmic rays shows that measurement vs altitude has been important in illuminating the subject. The measurement of residual ionization vs altitude by Hess and by Koehorster in 1912 gave the first positive evidence of the extraterrestrial nature of the cosmic radiation. Later, the measurements of Bowen, Millikan, and Neher of ionization vs altitude at various latitudes indicated the charged-particlelike character of the primaries and gave an energy spectrum for the primary radiation. At present there remain important unsolved problems; the mesatron component increases to the highest altitudes to which measurements have been made, yet its radioactive character insists that it is a secondary and therefore that it must eventually decrease; there is reported an overabundance of soft component at higher altitude; primary particles and their basic interactions (at energies 10,000 times the highest now sought for in man-made machines), which produce the soft and mesatronic secondaries appear to be largely observable only above the highest balloon flights.

This paper described the G. M. telescope of the type that Schein has used. This telescope measures total ionizing flux and compares the penetrating ionizing flux with the penetrating nonionizing flux, which converts in 2 cm of lead. The paper also described the arrangement used in the V-2 and presented a short discussion of the results obtained. There was indicated a need for additional verification, because of a rather large and unexpected presence of a nonionizing component of the primaries, or energy greater than 10^9 *EV* and capable of converting in 2 cm of lead.

Finally, there was presented a general description of data recovery from such rocket flights including results of aerodynamic spoiling to obtain lower landing speeds for the recovery of mechanical recorders, air sample bottles, cameras, spectrographs, etc. (*Author's abstract.*)

H. E. NEWELL, Naval Research Laboratory: *Exploration of the upper atmosphere by rockets, Pt. 2.*—The principal features of the V-2 rocket and its usefulness as a vehicle for upper-atmosphere experimentation were discussed. Following a review of the general aspects of upper atmosphere research including a discussion of the recovery problems, there was a discussion of the Naval Research Laboratory's work on solar spectroscopy, cosmic rays, pressure measurements, and ion-density measurements in the ionosphere. The paper was illustrated by means of slides pertaining to the October 10 V-2 flight at White Sands, N. Mex. (*Author's abstract.*)

1274th Meeting

The 1274th meeting was held in the auditorium of the Cosmos Club, January 4, 1947, President MOHLER presiding.

The retiring president, FRANCIS M. DEFANDORF, National Bureau of Standards, delivered his presidential address on the subject *The measurement of high voltage.* This address will be published in full in the JOURNAL.

1275th Meeting

The 1275th meeting was held in the auditorium of the Cosmos Club, January 18, 1947, President MOHLER presiding.

Program: R. S. BURINGTON, Bureau of Ordnance: *The concept (and misconcept) of equivalence.*—This paper in expanded form is published in this number of the JOURNAL (38: 1–11. 1948).

1276th Meeting

The 1276th meeting was held in the auditorium of the Cosmos Club, February 1, 1947, President MOHLER presiding.

Program: JAMES M. KLAASSE, Naval Ordnance Laboratory: *Airborne magnetometer in geophysical exploration, Pt. 1.*—The magnetic airborne detector AN/ASQ-3A was developed by the Naval Ordnance Laboratory and the Bell Telephone Laboratories and was produced by the Western Electric Co. for use in the U. S. Navy's Bureau of Aeronautics for locating submarines from aircraft. Modified systems of this type have been used extensively by the Naval Ordnance Laboratory and the U. S. Geological Survey in airborne geophysical surveys throughout the United States and in Alaska.

In the magnetometer described, detection of a magnetic field employs an inductor with nearly ideal magnetization and saturation characteristics and negligible hysteresis. When the inductor winding is driven well beyond saturation field for the core material by a sine-wave current, the resulting distortion of flux wave-form produces harmonics of the driving frequency. The even-harmonic content is proportional to the magnetic field applied along the inductor axis. The second harmonic is selected by suitable filtering. Three such inductors are arranged mutually perpendicular. Two of these are used in a servo system to maintain automatically the axis of the third along the direction of the total field, and also to compensate for flight errors in the orientation system. A controlled variable direct current is supplied to the third inductor winding to suppress the total field to a small fraction of the earth's field. The low-frequency response of the system permits continuous recording of the earth's magnetic field intensity and anomalies as small as 10^{-5} gauss (1 gamma) while airborne. (*Author's abstract.*)

F. KELLER, U. S. Geological Survey: *Airborne magnetometer in geophysical explorations, Pt. 2.*—The adaptation by the Geological Survey in cooperation with the Naval Ordnance Laboratory of the AN/ASQ-3A Magnetic Airborne Detector to problems of exploration in geophysics has made it possible to produce

maps of large areas showing total intensity variations of the earth's magnetic field with greater accuracy and speed and with less expense than by ground measurements.

The U. S. Geological Survey obtains the data by towing the magnetic detector element behind a twin-engined airplane in a streamlined housing called a "bird." Variations in magnetic intensity are recorded on a tape in the plane. The location of the plane is determined at all times by a gyroscopically stabilized Sonne continuous strip camera. A system of electrically operated counters and edge markers make it possible to correlate recognizable ground check points with the strip film and magnetometer record.

Magnetic surveys of over 120,000 square miles in areas which covered extreme contrasts of geological and magnetic environments have proved the value of the airborne magnetometer as a reconnaissance tool in exploration for mineral resources. (*Author's abstract.*)

1277th Meeting

The 1277th meeting was the occasion of the Sixteenth Joseph Henry Lecture and was held in the auditorium of the U. S. National Museum, February 15, 1947, President MOHLER presiding.

Program: JESSE W. BEAMS, Professor of Physics in the University of Virginia: *High centrifugal fields.* This address has been published in full in the JOURNAL **37**: 221–241. July 1947.

1278th Meeting

The 1278th meeting was held in the auditorium of the Cosmos Club, March 1, 1947, President MOHLER presiding.

Program: U. FANO, National Bureau of Standards: *Contributions of physics to biology, Pt. 1.*—The borderland between physics and biology is today the subject of widespread interest, especially from the side of young physicists, who think of making it their main line of work. It seems timely, therefore, to examine critically which specific, actual or potential, lines of endeavor should go under the name of biophysics. A few lines are well defined, such as: (*a*) the design, production, and employment of physical tools which help in solving biological problems; this is primarily a branch of applied physics; (*b*) the investigation of biological problems which involve physical measurements and tools; this requires knowledge of physical apparatus and techniques belonging primarily to biology as far as its motivation and methodology are concerned; (*c*) the participation of workers with training and experience in physics in the investigation of biological problems; this has often proved extremely effective.

It should be stressed that the field of endeavor is a biological one and physics plays no further part than lending ways of thought and methods of approach to problems. (*Author's abstract.*)

G. GAMOW, The George Washintgon University: *Contributions of physics to biology, Pt. 2.*—Until comparatively recent time the phenomena of life were so widely separated from familiar physical and chemical phenomena in inorganic matter that it seemed that the gap between the two could never be covered. This led to various "vitalistic" theories which insisted that the phenomenon of life is *principally* different from the ordinary physical phenomena and requires for their explanation some peculiar force known as "vis vitalis."

The recent progress of biology seems to cover the existing gap. In fact, the things like *viruses* and *genes* seem to represent the "missing links" between organic and inorganic matter. Although there is little doubt that *viruses* and *genes* represent the ordinary (although very complex) chemical molecules obeying the ordinary laws of quantum chemistry, they are also attributed to all basic properties of living organisms.

It is time now to attack the problem of these elementary living organisms from the purely physical point of view, and, while the biologists dig deeper and deeper into the properties of these entities from the complex and of biological forms, the physicist may be expected to approach the problem from the other end and "build up" the theory of gene and virus molecules on the basis of our present vast knowledge concerning the properties of atoms and atomic combinations. Just as the hydrogen atom represents the simplest model of atomic structure, and the deuteron the simplest nucleus, virus-particles are most probably the simplest biological models which can be treated theoretically.

Although there are still tremendous difficul-

ties ahead, we may not be so far from the possibility of constructing the model of the simplest living unit on the basis of purely atomic considerations. (*Author's abstract.*)

1279th Meeting

The 1279th meeting was held in the auditorium of the Cosmos Club, March 15, 1947, President MOHLER presiding.

Program: S. E. FORBUSH, Department of Terrestrial Magnetism: *Cosmic rays from the sun?*—During the past 10 years three unusual and sudden increases in cosmic-ray intensity, lasting several hours, have been observed simultaneously in different parts of the world except at the Equator where no increase was observed. All three increases began nearly simultaneously with unusually long and intense radio-fadeouts and solar-flares. The cosmic-ray increases were similar and simultaneous on the day and night side of the earth. Magnetograms from several magnetic observatories indicate that the increase in cosmic-ray intensity can not be ascribed to changes in the earth's magnetic field. While the increases in cosmic-ray intensity might be ascribed to changes in the sun's general magnetic field which would permit more cosmic rays from outer space to reach the earth, such mechanism should be equally effective whether the solar-flare occurred in the front or back side of the sun. This with other arguments indicates that changing magnetic fields associated with a sunspot or flare may act as a magnetic accelerator for charged particles. Similar processes on stars might account for all cosmic rays. (*Author's abstract.*)

P. H. ABELSON, Department of Terrestrial Magnetism: *The transuranic elements.*—The paper reviewed the facts leading to the discovery of neptunium. The nuclear and chemical properties of the transuranic elements were discussed. Possible methods of producing elements of higher atomic number than 96 were described. These included the bombardment of uranium or plutonium with high speed carbon, oxygen, or other nuclei. (*Author's abstract.*)

1280th Meeting

The 1280th meeting was held in the auditorium of the Cosmos Club, March 29, 1947, President MOHLER presiding.

Program: HUGH L. DRYDEN, National Bureau of Standards: *Exploring the fundamentals of aerodynamics.*—This paper has been published in full in the JOURNAL 37: 145–156. May 1947.

1281st Meeting

The 1281st meeting was held in the auditorium of the Cosmos Club, April 12, 1947, President MOHLER presiding.

Program: A. H. BENNETT, American Optical Co.: *The phase contrast microscope.*—The older microscopic methods are particularly useful for certain types of specimens, but for materials whose details have little absorption differences but differences in optical path, the phase method has advantages. In phase microscopy such microscopic details are imaged as brightness differences to which the eye or photographic plate are sensitive. Work leading to phase microscopy was done by Abbé (prior to 1892), Bratuschek (1892), Rheinberg (1904), and Conrady (1905). Zernicke (1935) described the application of the phase contrast method to microscopy. Burch and Stock (1942) described their results using simplified equipment. Study of the theory, application, and apparatus for the method was begun by Richards, Osterberg, Jupnik, and the writer in 1941. In phase microscopy an annular ring placed near the lower focal plane of the substage condenser acts as a secondary light source. This ring is imaged by the condenser and the objective onto a diffraction plate which by means of evaporated metal and dielectric films, alters the amplitude and phase relationships between the light undeviated by the specimen and the diffracted light. The light distribution in the image formed under the above conditions is determined by means of diffraction theory. (*Author's abstract.*)

O. W. RICHARDS, American Optical Co.: *Applications of the phase contrast microscope.*—While theoretical considerations indicate the possibility of a large number of diffraction plates, a relatively small number serve the needs of practical microscopy. Bright contrast is useful in counting and for finer details. Dark contrast is useful and sometimes is preferred as the image resembles that from stained preparations. Detail is brought out in living cells, emulsions, and on transparent surfaces. Photomicrographic records are possible and stereophotomicrographs reveal detail in three dimensions. When stained or pigmented, speci-

mens do not have high contrast, it is possible to add phase contrast of greater visibility. All four types of Spencer diffraction plates have proved of use in microscopy. Replicas of Formvar, acetate, or silica surfaces may be examined with the phase microscope which opens a new field for investigation. Photomicrograph lantern slides were shown of typical applications including living unstained epithelial cells, bacteria, fungi, protozoa, and spermatozoa; unstained tissues, chromosomes, and malaria parasites; stained chromosomes, urine casts, emulsions, wool, rayon, paper, and replicas of steel surfaces. (*Author's abstract.*)

W. R. DURYEE, Department of Terrestrial Magnetism: *A film on the mechanism of cell division.*—The paper consisted essentially of the showing of a film prepared by K. Michel of the Zeiss Co. using phase contrast lenses and time-lapse photography.

The material photographed consisted of living spermatocytes of the grasshopper *Psophus stridulus* Linnaeus isolated in a physiological salt solution. Since time lapse photography was used, processes lasting over 5 to 15 hours were reviewed in a few minutes. In addition the phase contrast lenses brought out many details, relationships, and structural contrast that the human eye unaided could not see in normally transparent cells.

Major sequences in the film were, first, *prophase* changes in the nucleus. Chromosomes were visible shortening and thickening in their colloidal matrix. Arrangement of chromosomes on the spindles was followed by grouping of mitochondria in the mid-cytoplasm, next in the *metaphase* details of spindle lateral spread preceded actual elongation. Thirdly, separation of the chromosomes and other cytoplasmic movements during *anaphase* were shown. Final stages of cytoplasmic fission and *telophase* reconstitution of the daughter nuclei were clearly photographed.

A remarkable sequence showed continual elongation of spindle substance even after each cell had divided. Concomitant sol-gel reversals of the polar surfaces were evident. New details of spermatocyte transformation into the early spermatic concluded the picture.

The film has been adopted by the Surgeon General's office as a medical technicians' training film and was shown through the courtesy of the War Department. (*Author's abstract.*)

1282d Meeting

This was a joint meeting with the Washington Academy of Sciences, held in the auditorium of the Cosmos Club, April 17, 1947.

Program: P. W. BRIDGMAN, Professor of Physics in Harvard University.—*High pressures and their effects.*

1283d Meeting

The 1283d meeting was held in the auditorium of the Cosmos Club, April 26, 1947, President MOHLER presiding.

Program: PAUL F. WACKER, National Bureau of Standards: *Heat capacities of gases.*—Experimental heat capacity data for gases are useful both for the calculations of heat requirements in industrial operations and in checking statistical calculations of heat capacity, heat content, entropy, and free energy of complicated molecules. These calculations are made for extremely wide temperature ranges and permit calculations of yields of reactions as well as heat requirements.

Heat leaks were made negligible by the use of thermostated radiation shields and a carefully designed calorimeter. This absence of heat leaks made high precision possible and reduced consistent errors to very small values. The working time was also reduced, since ordinarily it is necessary to make measurements as a function of flow rate in order to correct for heat leak. As a check for consistent errors, the heat capacity of oxygen was measured and compared with highly accurate values calculated statistically from spectroscopic data. The values at $-30°C$ and $+90°C$ differed from the spectroscopic data by 0.06 percent and 0.10 percent, respectively, while the experimental value at $+40°C$ did not differ from the spectroscopic data by a significant amount. Consideration of the data obtained for oxygen and the known sources of error indicates that the measurements with the apparatus have a probable error of 0.06 percent or 0.07 percent. (*Author's abstract.*)

W. H. AVERY, Johns Hopkins Applied Physics Laboratory: *Infrared spectra at low temperatures.*—Difficulties caused by overlapping of the infrared absorption bands restrict the application of these spectra to the analysis of complex hydrocarbon mixtures. Theoretical considerations suggested that these difficulties

might be minimized by observing the spectra at low temperatures, since the width of the absorption bands is predicted to be proportional to the square root of the absolute temperature. Using a cell with a reflecting bottom surface which could be immersed in liquid hydrogen, upon which films were condensed, spectra were obtained of a number of saturated hydrocarbons. The spectra were found to show the predicted narrowing of the absorption bands and a striking decrease in overlapping of the bands. Quantitative application of the method was interfered with, however, because of the scattering due to small crystals of the condensed hydrocarbons. A change from the gaseous to solid phase did not produce any significant shifts in the position of the bands of saturated hydrocarbons, but there were some indications that overtone and combination bands were changed in intensity by the condensation. The use of liquid helium was suggested for a further improvement in resolution of the spectra. A theoretical analysis of probability of the overlapping bands in complex mixtures showed that the use of low temperatures might be expected to increase tremendously the number of mixtures susceptible to infrared analysis. (*Author's abstract.*)

1284th Meeting

The 1284th meeting was held in the auditorium of the Cosmos Club, May 10, 1947, President MOHLER presiding.

Program: D. H. MENZEL, Harvard College Observatory: *Problems of the sun.*—Our rapidly accumulating observational data on the sun have served to focus our attention on the many unsolved problems of the solar atmosphere. Although the surface layers appear to possess a temperature of about 6,000°C, the temperature and excitation rise rapidly in the higher levels. In the upper chromosphere and prominences, the temperatures range from 10,000°C to 25,000°C. In the solar corona, temperatures may attain values in excess of a million degrees. There are many additional problems such as the support of the prominences and chromospheric layers and the explanation of the gases in the solar atmosphere. Thus far, we have no completely satisfactory theory of any of these phenomena.

The solar observations made regularly at the High Altitude Observatory of the Harvard University and the University of Colorado, located at Climax, Colo., have provided the astrophysicists with new indices of solar activity. Even though we do not yet understand the basic physical processes, we realize that marked changes in the output of solar ultraviolet radiation accompany the prominences and coronal disturbances. These ultraviolet variations, in turn, affect the ionosphere, the earth's magnetic field, and the luminosity of the night sky. There is also a high probability that there may be a relationship between solar activity and terrestrial weather. The ozone layer of the earth's atmosphere acts as a medium to transmit solar impulses from the upper to the lower atmospheric levels.

Study of the sun, for the above-mentioned practical reasons, assumes an increasingly important place in science. Accurate forecasting of radio-propagation conditions or of weather in general would possess immense economic value. For example, if only we could tell the farmer that the next growing season will be hot or cold, wet or dry, late or early, many losses would be avoided.

For the long-range view, study of solar radiation has additional practical applications. No natural process is now replacing the stock of oil and coal, produced over geological ages. An understanding of the sun and solar processes will help us to utilize more effectively the solar radiation, upon which we shall eventually have to depend for heat and power. (*Author's abstract.*)

1285th Meeting

The 1285th meeting was held in the auditorium of the Cosmos Club, May 24, 1947, President MOHLER presiding.

Program: A. E. RUARK, Johns Hopkins Applied Physics Laboratory: *Behavior of particles in scattering and absorbing media.*

A. J. SHNEIDEROV presented an informal communication regarding gravitation.

The president announced the election of the following Committee on Communications for the season 1947–48: G. B. SABINE, *chairman*, R. C. HERMAN, and THOMAS CARROLL.

WALTER L. CHENEY, *Recording Secretary.*